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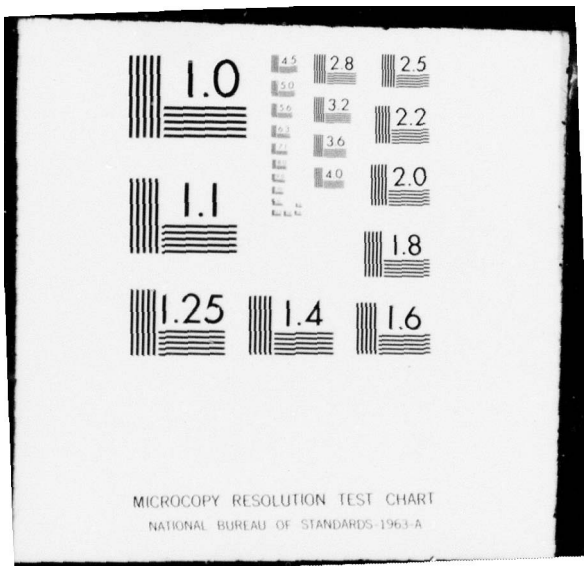
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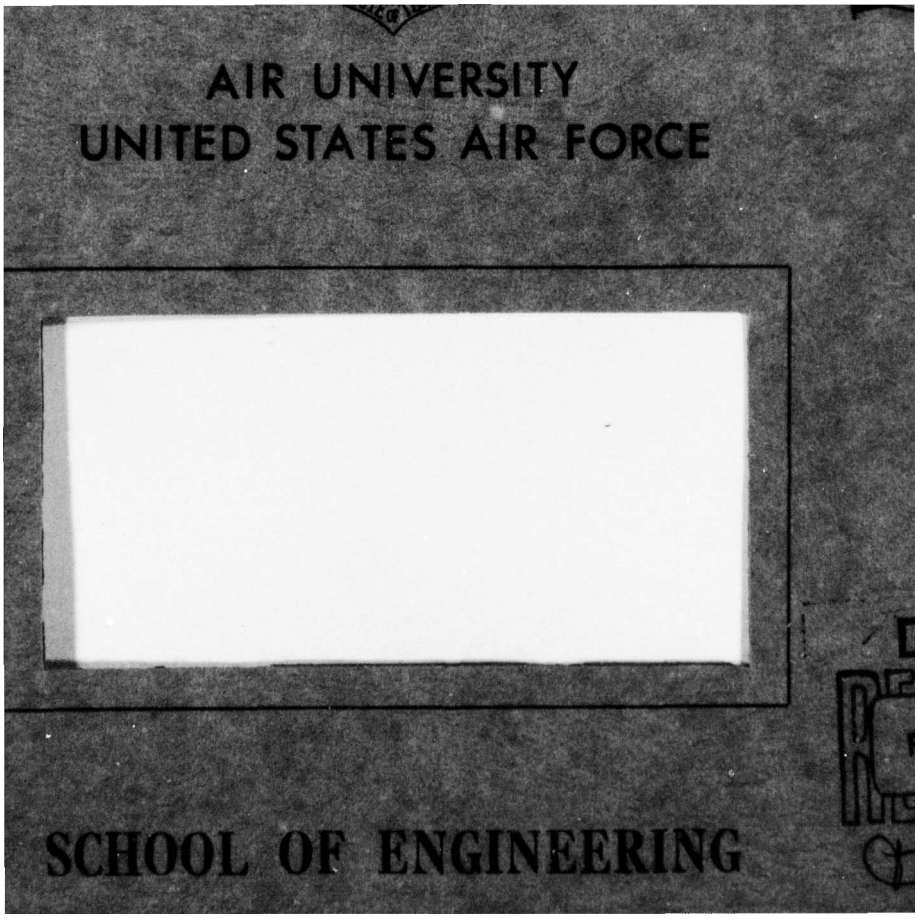
AIR UNIVERSITY
UNITED STATES AIR FORCE
SCHOOL OF ENGINEERING

A PRELIMINARY DESIGN FOR A NEUROPSYCHOPHYSIOLOGICAL HUMAN ENGINEERING TEST BATTERY

THESIS

AFIT/GCS/BE/78-14

Robert E. Norris
Capt USAF

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A PRELIMINARY DESIGN FOR A NEUROPSYCHOPHYSIOLOGICAL HUMAN ENGINEERING TEST BATTERY.

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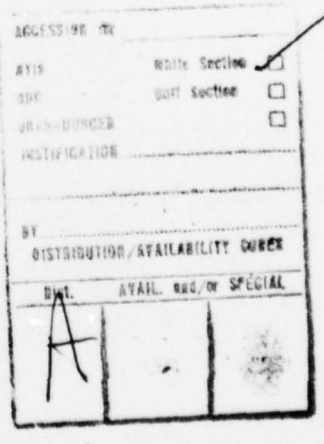

by

(10) Robert E. Norris, ~~B.S.E.E.~~

Captain USAF

Graduate Electrical Engineering

(11) December ~~1~~978

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Preface

This report presents a preliminary design for a Neuropsychopsysiological Human Engineering Test Battery. The purpose of this data processing system is to aid research being conducted at the 6570th Aerospace Medical Research Laboratory in the area of human performance evaluation. The design of this system was developed through the use of structured design techniques. Although these techniques have been developed primarily for software development, they are sufficiently general that they can also be applied towards the development of hardware. As a result, this preliminary design addresses both the hardware and the software considerations that need to be examined in the development of this test battery.

For their guidance in this project I would like to express my thanks to my thesis committee: Dr. Matthew Kabrisky, Dr. Pete Miller, and Capt Frank Kirschner. I would also like to extend a very special thanks to LtCol Bob O'Donnell for his sponsorship and support in this project and to his staff at the 6570th Aerospace Medical Research Laboratory for their assistance.

Robert E. Norris

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Abstract

A preliminary design for a computer based Neuropsychophysiological Human Engineering Test Battery is developed. This system provides for the automated administration of a battery of tests designed to measure human performance as reflected in the electroencephalogram, cortically evoked potentials, and other psychophysiological measures of performance. This system will be capable of recording and analyzing up to 100 channels of electrophysiological data.

System design is developed through the use of structured design techniques. The initial stage of the design process, the requirements definition phase, is developed with the aid of the Structured Analysis and Design Technique (SADT) developed by SofTech, Inc. The remainder of the design, the actual preliminary design, is developed through the use of general structured design techniques.

The resulting system design is centered around a main computer which coordinates system activities, stores experimental data, analyzes experimental data, and generates displays and final reports. Initial data collection is achieved through the use of multiple microprocessor based data acquisition units. The subject station, where stimuli are generated and subject responses take place, is also under microprocessor control. Provision is also made for transmitting data from a remote location.

A PRELIMINARY DESIGN FOR A NEUROPSYCHOPHYSIOLOGICAL HUMAN ENGINEERING TEST BATTERY

I Introduction

Background

The U.S. Air Force is currently conducting research in the area of Human Engineering in order to better utilize the capabilities of the human operator in an aerospace system. This effort is in recognition of the fact that the state of aerospace technology has advanced to the point where it is now possible to design a system whose capabilities exceed those of the human being who must interact with that system. For certain tasks, the human operator is one of the weakest components in some systems. At the same time he may be the most important component of that system since there are no systems presently available that are capable of totally replacing the judgement of the human operator. As a result, a considerable amount of attention is being devoted to creating the proper interface between the human and the machine.

Solving this human interfacing problem is a primary task at the Human Engineering Division of the 6570th Aerospace Medical Research Laboratory located at Wright-Patterson Air Force Base in Dayton, Ohio. A fundamental hypothesis of the research effort being conducted in this organization is that in order to properly interface the human operator to a machine, it is first necessary

to understand the functioning of the various subsystems of the human being. One level of effort is the investigation of how the human brain functions in an operational environment. It is believed that some insight into the functioning of the brain can be obtained by examining the electrical activity of the brain that can be detected by electrodes placed on the surface of the scalp.

There are two basic types of waveforms that are normally studied in this type of investigation of brain activity: the general electroencephalogram (EEG) and, a particular class of electroencephalogram, the evoked potential (EP). The electroencephalogram is a measure of the ongoing electrical activity in the brain and is not related to any particular stimulus. Evoked potentials, on the other hand, are the electroencephalographic activity of the brain that results from presenting a specific stimulus to the brain through one of the sensory channels. For example, a letter of the alphabet may be flashed on a screen in front of a subject thereby stimulating the visual centers of the brain.

Much of the work done in the area of electroencephalography has examined the simultaneous electrical activity of the brain at several locations on the scalp. The need for examining these waveforms at multiple sites of the brain is in recognition of the fact that information is not processed in one single location of the brain. Rather, information enters the brain at a fairly localized area and, through a network of very complex, interconnecting pathways, is then distributed throughout the brain in

accordance with information processing requirements. As a result, the brain processes information spatially as well as temporally and the electroencephalographer is interested in measurements along both of these dimensions.

In the past, the number of electrodes that can be monitored in such a study has been somewhat limited due to the technology of available data processing systems. With the advent of the microprocessor, however, it is possible to expand the total number of electrode outputs that can be examined at one time. Such an expanded capability will allow researchers the opportunity to obtain a more complete view of how the brain responds to various information processing tasks.

At the present time, the Human Engineering Division of the 6570th Aerospace Medical Research Laboratory is developing the Neuropsychophysiological Human Engineering Test Battery to address some of the problems outlined above. This test battery will consist of a series of tests designed to evaluate the functioning of the human brain under a variety of test conditions. In response to these tests, electrophysiological data from up to one hundred channels will be collected and analyzed. Therefore, in addition to the test battery itself, it will be necessary to develop a data processing system to perform data collection and analysis.

Current Research

Electroencephalography. A survey of the literature reveals a large amount of information in the area of electroencephalography. Included in this area of the literature is information pertaining to the theory of EEG signals, electrical characteristics and

specifications of EEG signals, laboratory techniques, laboratory equipment, data acquisition techniques, waveform pattern recognition, and data analysis techniques. As a result, there already exists a good foundation upon which the proposed Neuropsychophysiological Human Engineering Test Battery may be developed.

Publications by John (Ref 1), Donchin (Ref 2), Perry and Childers (Ref 3), Yegorova (Ref 4), and Regan (Ref 5) serve as excellent references, providing introductory material in the areas cited in the preceding paragraph. In particular, John's work in Neurometrics will serve as the primary point of departure for this paper.

John defines Neurometrics as an analytical approach which is "... based upon quantitative measurements of salient features extracted from electrophysiological data which reflect various aspects of brain function related to sensory, perceptual, and cognitive processes as well as to the structural and functional integrity of different neuroanatomical systems." (Ref 1:1). Traditionally, the evaluation of the EEG has relied upon the judgement of the electroencephalographer. Because of differences in experience and the somewhat subjective nature of these judgements there can be a wide variation in evaluations between electroencephalographers. In contrast, Neurometrics is an attempt to quantify what is known about the EEG so that more objective and reproducible evaluations about brain function can be made (Ref 1:1-5).

Various analysis techniques have been compiled by John. These techniques may be classified as either graphical or numerical in nature. The graphical analysis techniques are useful in providing

a convenient visual form of representing data. On the other hand, the numerical analysis techniques provide quantitative facts not readily apparent in graphical displays (Ref 1:30-50). A wide range of numerical analysis techniques are also presented by Perry and Childers (Ref 3:95-129).

In order to detect evoked responses, John presents a number of suitable pattern recognition methods. The two basic categories of pattern recognition that are suggested are template methods and cluster analysis. The template methods are used to match a sample waveform with a known prototype waveform. In those instances when a prototype is not readily available, cluster analysis is used to classify waveform samples based upon similarities with other waveform samples. It appears that both of these techniques will be useful in implementing a psychophysiological measure of brain function based on the evoked response (Ref 1:50-61).

In addition to developing the basic notion of Neurometrics and a corresponding battery of tests, John has also been involved in the development of a hardware system that will implement these ideas. This system is called the Digital Electrophysiological Data Acquisition and Analysis System (DEDAAS). While DEDAAS is a very impressive system, there are a number of drawbacks to the system which make it inappropriate for the Neuropsychophysiological Human Engineering Test Battery being proposed by the Aerospace Medical Research Laboratory. These drawbacks are itemized below:

1. The amplifiers used in DEDAAS do not have the bandwidth required to measure either brain stem evoked response or electromyogram.

2. DEDAAS is capable of monitoring no more than 24 channels of EEG data whereas the system being developed in this paper will be required to monitor up to 100 channels of EEG data.

3. The sampling rate of 200 samples/sec/channel is not high enough to adequately sample either the brain stem evoked response or the electromyogram.

4. DEDAAS does not presently have the capability for telephone or telemetered interactions.

5. DEDAAS is not capable of operating on a real time basis. In its current configuration it appears that data is first recorded in analog form after which editing and analog-to-digital conversion takes place. These techniques will have to be examined and probably modified to provide a quicker response from the data processing system (Ref 1:74-85).

While John's work is primarily directed towards clinical applications, his principles are equally applicable to the operational environment. Research along these lines is reflected in the work of Donchin. In this work, Donchin is developing techniques to extract evoked potentials from a single sample. The technique is referred to as a single trial signal extraction (STSE) technique and is based upon stepwise discriminant analysis (SWDA). As this technique is developed it is hoped that it may one day be incorporated into the man-machine environment of an operational system so that plant dynamics can be selectively modified to enhance overall system performance. It is desired that the system that will implement the Neuropsychophysiological Human Engineering Test Battery will be sufficiently general to

examine some of these concepts as well as work load assessment and other psychophysiological measures that are useful in describing cognitive processes in the operational environment (Ref 2).

Structured Design. Structured design is a concept currently being advocated in the software industry. It is an approach to design in which a system is defined in successively finer levels of detail. The term "top-down design" is normally associated with this design methodology.

One of the initial phases of system development is the analysis of the problem. A structured approach to analysis, called the Structured Analysis and Design Technique (SADT), has been developed by SofTech, Inc. (Ref 7, 8). While SADT is a technique primarily intended for software development, it is, because of its generality, equally effective in the development of systems requiring both hardware and software. The utility of this technique in the development of hardware/software systems is exemplified in the work of Maneely (Ref 9).

Following the analysis phase of system development is design. Structured design techniques developed by Constantine and Yourdon have proven to be useful in defining the overall system software structure of a design (Ref 6).

Statement of the Problem

The purpose of this paper is to develop a preliminary design for the data processing system that will implement the above Neuropsychophysiological Human Engineering Test Battery. As stated previously, this system will be required to collect and analyze electrophysiological data from up to one hundred channels.

In addition, this system will also be required to control the generation of test battery stimuli.

It is intended that this data processing system be as fully automated as possible. Yet, it is realized that there will be some level of user interaction required. User needs will dictate design decisions in this area. Along these lines, it is desired that this test battery operate in real-time or near real-time, i.e., test results should be available during the time interval between the conclusion of the current test and the beginning of the following test. This requirement for real-time operation will allow the user to modify test sequencing in response to the demands of the experimental environment.

The proposed data processing system will need to be flexible enough to adapt to a Neuropsychophysiological Human Engineering Test Battery that will be undergoing an almost constant evolutionary process. Initially, though, this system will be required to support the following tests: transient auditory evoked response, transient visual evoked response, steady state visual evoked response, epoch analysis of EEG, brain stem evoked response, and, of low priority, galvanic skin response, electromyogram, and electrocardiogram.

Scope of Effort

Due to the extensive nature of this problem, the scope of the research effort proposed in this paper will be limited to a preliminary design of the overall system hardware and software. With this constraint in mind, the following areas will be addressed:

1. Preliminary design of the hardware system required to process up to one hundred channels of electrophysiological data.

2. Discussion of storage medium required.

3. Discussion of signal processing techniques that will be useful in extracting quantitative features from recorded electrophysiological activity.

4. Discussion of analytical procedures required.

5. Discussion of display methods.

General Approach

A top-down design approach will be used to arrive at the system design for the proposed Neuropsychophysiological Human Engineering Test Battery. In this approach the overall system objectives or "top" is defined first. This "top" is then further broken down into successively finer levels of detail. The resulting hierarchial design structure can then serve as a basis for dividing the system design up into smaller more manageable work units from which system development may proceed. At the same time, this structured approach to design will insure that these smaller work units, once completed, will be properly integrated into the overall system since the relationships between these various system sub-units are defined right from the start of the design process. Because of the demonstrated appropriateness of the technique, many of the principles of SADT have been used in the problem analysis of the Neuropsychophysiological Human Engineering Test Battery. Following this problem analysis will be a preliminary design of the test battery developed with the structured design techniques advocated by Constantine and Yourdon.

II Neuropsychophysiological Human Engineering Test Battery

Before proceeding into the analysis and design phases of this project it would be best to discuss the various tests that will be included in the test battery and the different kinds of electrophysiological signals that will be measured during this test battery. Such a discussion will serve to define the problem environment. Accordingly, the following psychophysiological tests will be examined: epoch analysis of EEG, transient auditory evoked response, transient visual evoked response, steady state visual evoked response, brain stem evoked response, electromyogram, electrocardiogram, and galvanic skin response.

Epoch Analysis of EEG

The electroencephalogram represents the aggregate electrical activity of the cerebral cortex of the brain. The voltage measured in an EEG may range as high as 200 microvolts peak-to-peak. Additionally, the EEG may be characterized by rhythmic repetitions which have caused researchers to divide the overall electroencephalogram into several natural frequency bands: low delta (0.5-1.5 Hz), high delta (1.5-3.5 Hz), theta (3.5-7 Hz), alpha (7-13 Hz), low beta (13-19 Hz), high beta (19-25 Hz), and gamma (25-40 Hz) rhythms. While there are several competing and unverified theories as to what causes the electroencephalogram and what causes the various rhythms within the electroencephalogram,

it is generally recognized that the EEG reflects the functional condition of the cerebral cortex (Ref 4:1-11).

Physicians and researchers normally examine EEG's manually by paging through the EEG record and identifying those portions of the record that deviate from normal. Any abnormal sections of the record are then examined further to arrive at a diagnosis. In computerized epoch analysis a thirty second segment of the EEG record is arbitrarily selected and a spectral analysis of that segment is performed. The resulting spectrum gives an indication of the frequency content of the EEG record from which diagnoses or experimental conclusions may be drawn. There has been much work done in the area of feature extraction from electroencephalograms. Through this work it is hoped that computerized epoch analysis of EEG will approach more closely the selective process used by physicians and researchers to analyze EEG (Ref 10:642-643).

Transient Evoked Potentials

Transient evoked potentials are that part of the EEG waveform that are induced by a stimulus delivered to the brain through one of the sensory channels. These evoked potentials (EPs) occupy roughly the same frequency band as normal EEG and are approximately 10% of the overall amplitude of the normal EEG. Consequently, the signal of interest, the EP, is buried in the overall EEG so that it is usually very difficult to identify the evoked potential from a single waveform. The analysis technique most commonly used is an averaging or summation processes in which many evoked potentials

are summed together. The evoked potential, which is keyed by the stimulus will then "grow" out of the noise during this summation process while the larger EEG, which is essentially random, "fades" away since it increases only by $\sqrt{N}$, where N is the number of samples taken. The resulting average evoked potential then serves as an indication of the functional condition of the specific sensory channel being examined (Ref 11).

Generally, the first 250 msec of the transient evoked potential is believed to represent the encoding process that the brain uses before analyzing the stimulus information. The remainder of the EP (roughly 1 sec) is thought to be related to the cognitive processes that take place within the brain after reception of the stimulus and to a rythmic after-discharge in which the brain recovers from this evoked activity (Ref 3:7).

Within the time interval of the evoked potential there are several peaks (also referred to as components of the waveform) which mark specific events of the information processing activity that takes place. These components are usually identified by a ⟨character⟩ ⟨number⟩ designation where the ⟨character⟩ indicates the polarity of the component and the ⟨number⟩ refers to the latency (in time) of the component with respect to stimulus presentation. While the amplitude of the various peaks may vary between subjects or even between trials for the same subject, peak latency is a very reliable measure of the electroencephalographic activity that is evoked by the stimulus presentation. As a result, peak latency is usually examined more critically than peak amplitude. Some of the more notable components of the transient evoked potential are:

N100. This component results from the presentation of moderate and high intensity stimuli. It is believed that the amplitude of the N100 component offers some indication of the degree to which the subject is attending selectively to the modality in which the stimuli are presented.

N190. The N190 component occurs whenever a rare, or unexpected event takes place.

P300. The P300 component of the transient evoked potential occurs in response to task-relevant, rare stimuli and seems to be related to the cognitive processing of information contained in these stimuli (Ref 2:1-3).

Both the auditory and visual transient evoked responses will be used in the Neuropsychophysiological Human Engineering Test Battery. It is desired that there be a capability to identify all major peaks in these waveforms with the P300 component being of prime interest. The transient auditory evoked response will be utilized as a secondary test for assessing workload and operator stress while the transient visual evoked response will be used in the study of problems in visual information processing and display design.

Steady State Visual Evoked Response

In the steady state visual evoked response, the visual system is stimulated at a fixed frequency. The stimulus used can take many forms but is usually simple in nature, e.g., a flashing on-off checkerboard pattern. The resulting waveform is then averaged in the same manner that the transient evoked response is averaged.

This averaged waveform is then notch filtered at the same frequency as the stimulus frequency and a reading is made on the amplitude and phase of the resulting sinusoidal component. Additionally it may be desired to examine the steady visual evoked response at different stimulation frequencies and possibly the harmonics of these stimulation frequencies. The resulting amplitude-frequency and phase-frequency plots then describe some aspect of the dynamic nature of the brain as it responds to visually presented stimuli. This test has its application in assessing such visual sensory functions as visual acuity, color sensitivity, contrast, and visual system integrity (Ref 11).

Brain Stem Evoked Response

The brain stem evoked response (BSR) is induced by a series of audible "clicks" presented to the subject at the rate of 10/sec. The resulting electroencephalographic activity is then filtered below 80 Hz and above 3000 Hz. By establishing a low frequency cut-off of 80 Hz for the BSR it is possible to filter out virtually all of the normal EEG which can be several thousand times the amplitude of the brain stem activity. As a result, eliminating the normal EEG from the signal makes signal extraction much easier. The upper frequency limit of 3000 Hz is used because it is believed that brain stem activity does not have any significant frequency components above this limit. After this filtering process the remaining signal is then averaged to further reduce the effects of noise. This averaged waveform is the brain stem

evoked response and is characterized by a series of seven peaks that appear during the first 10 msec following each click stimulus (Ref 12).

The brain stem evoked response is an objective measure of the functional state of the brain stem. Peak amplitude measurements are of secondary importance in this response due to the high variability of this measure. A more stable measure is the latencies of the individual peaks. Consequently, peak latency is normally used in evaluating brain stem function. Typical values for both peak latency and amplitude have been tabulated in Starr and Achor (Ref 13:763) for a 65 dB sensation level stimulus. It should be noted, though, that these values change with the sensation level of the stimulus. As a result, trend information resulting from varying sensation levels is also a useful measure of brain stem activity.

Other Psychophysiological Indices

Other psychophysiological measures of potential interest are: electrocardiogram, electromyogram, and galvanic skin response. Due to their general failure in providing a great deal of operationally useful information in the past, these techniques are considered to be of low priority.

Psychophysiological Electrical Characteristics

Before beginning a design of a system to analyze electrophysiological data it is first necessary to understand the general nature of these signals. For without this kind of information it would be impossible to address such issues as amplifier gain, bandwidth, sampling rate and other design considerations. The

electrophysiological signals being considered in this study are affected by many variables so that it is difficult to describe a typical waveform for each of the responses. For this reason researchers usually report only rough guidelines concerning waveform electrical characteristics. Nevertheless, some design criteria need to be established; the following Table I has been compiled (Ref 3:25, Ref 5:74-83, Ref 11, Ref 12:30, Ref 14:653, Ref 15:717, Ref 16:1397, Ref 17:7).

Table I

Electrical Specifications
for
Electrophysiological Signals

Signal Type	Signal Range (Peak-to-Peak)	Frequency Range
Electroencephalogram	200 μv	0.5-40 Hz
Trans. Vis. Evoked Resp.	20 μv	0-50 Hz
Trans. Aud. Evoked Resp.	20 μv	0-50 Hz
Steady State Vis. Evoked Response	20 μv	0-60 Hz
Brain Stem Evoked Resp.	0.50 μv	80-3000 Hz
Electrocardiogram	1 mv	0-100 Hz
Electromyogram	400 μv	0-1000 Hz
Galvanic Skin Response	(1kΩ -500 kΩ)	0-1 Hz

(Ref 3:25, Ref 5:74-83, Ref 11, Ref 12:30, Ref 14:653, Ref 15:717, Ref 16:1394, Ref 17:7)

III System Analysis

The requirements definition or analysis phase makes up one of the early stages in a system's life cycle. This phase is intended to serve as a transition phase between the initial system concept and the actual design. The purpose of the requirements definition phase is to describe precisely "what" the system is supposed to do. At this stage of the system life cycle there is very little attention devoted to "how" the system is to be implemented. "How" the system is to be implemented is more properly reserved for the design phase of the system life cycle.

The major objective of the requirements definition phase is to develop a model of the proposed system. One method of model development is Structured Analysis (SA) which is characterized by the top-down approach referred to earlier in this paper. Most of the SA languages developed in recent years are computer based. One SA language, the Structured Analysis and Design Technique (SADT) developed by SofTech, Inc., is a manual method of performing the function of system analysis. It has the advantages of convenience and economy over the computer based languages and is still a very effective way of representing the model of a system. Because of these advantages, many of the principles of SADT are used in this paper.

The conventions of SADT are described in several publications by SofTech (Ref 7;8). In addition, a brief summary of some of the major conventions of SADT have been included in Appendix B of this paper.

There will be one major departure from the SADT technique as it is applied in this paper. Experience at the Air Force Institute of Technology has shown that the SADT data model provides little useful information over the information already contained in the SADT activity model. Consequently, only the activity model is presented in this paper (Ref 9).

SADT Activity Model

The remainder of this chapter is devoted to the SADT activity model of the Neuropsychophysiological Human Engineering Test Battery. The model was based on the user's manual included in Appendix A of this paper. The model is divided into three basic modes of operation: define experiment mode, execute experiment mode, and analysis mode. This development is similar to the approach taken by Liebach in his model for a Multi-Mode Matrix Display (Ref 18).

During system operation errors are handled in a number of ways. User inputs (commands and associated parameters) are validated by the system software. In the event of an error in user input, the input will be rejected, an error message will be printed out, and the user will be required to re-enter the input. Errors occurring due to equipment malfunction will be detected by the system software and an error message will be printed out on the experiment display. The experimenter must then decide whether to intervene or allow the experiment to proceed in its degraded condition.

In the test definition mode of operation, individual tests are defined and combined into a sequence of tests. This sequence

of tests then serves to control the execution of the experiment and the analysis after the experiment. In order to maintain system flexibility there is provision for updating the test sequence during experiment execution by interposing additional tests into the test sequence. This updated test sequence then serves as a record of the actual sequence of tests performed during an experiment. In addition, there is provision for programmed intervention such as artifact rejection.

The SADT activity model of this system follows:

Node	Title
A-0	Administer Neuropsychophysiological Human Engineering Test Battery
A0	Administer Neuropsychophysiological Human Engineering Test Battery
A1	Define Experiment
A11	Get Valid Command
A12	Get Valid Experiment Definition Parameters
A13	Perform Library Function
A14	Display Experiment Definition Interactions
A2	Execute Experiment
A21	Generate Experiment Sequence
A22	Generate Experimental Data
A222	Subject Responds to Test
A23	Process Experimental Data
A231	Collect Data
A232	Perform Computational Signal Processing
A233	Analyze Data
A234	Display Results
A3	Perform Analysis Function
A31	Perform Computational Signal Processing
A32	Perform Analysis
A33	Produce Reports

Figure 1. Activity Diagram Node Index

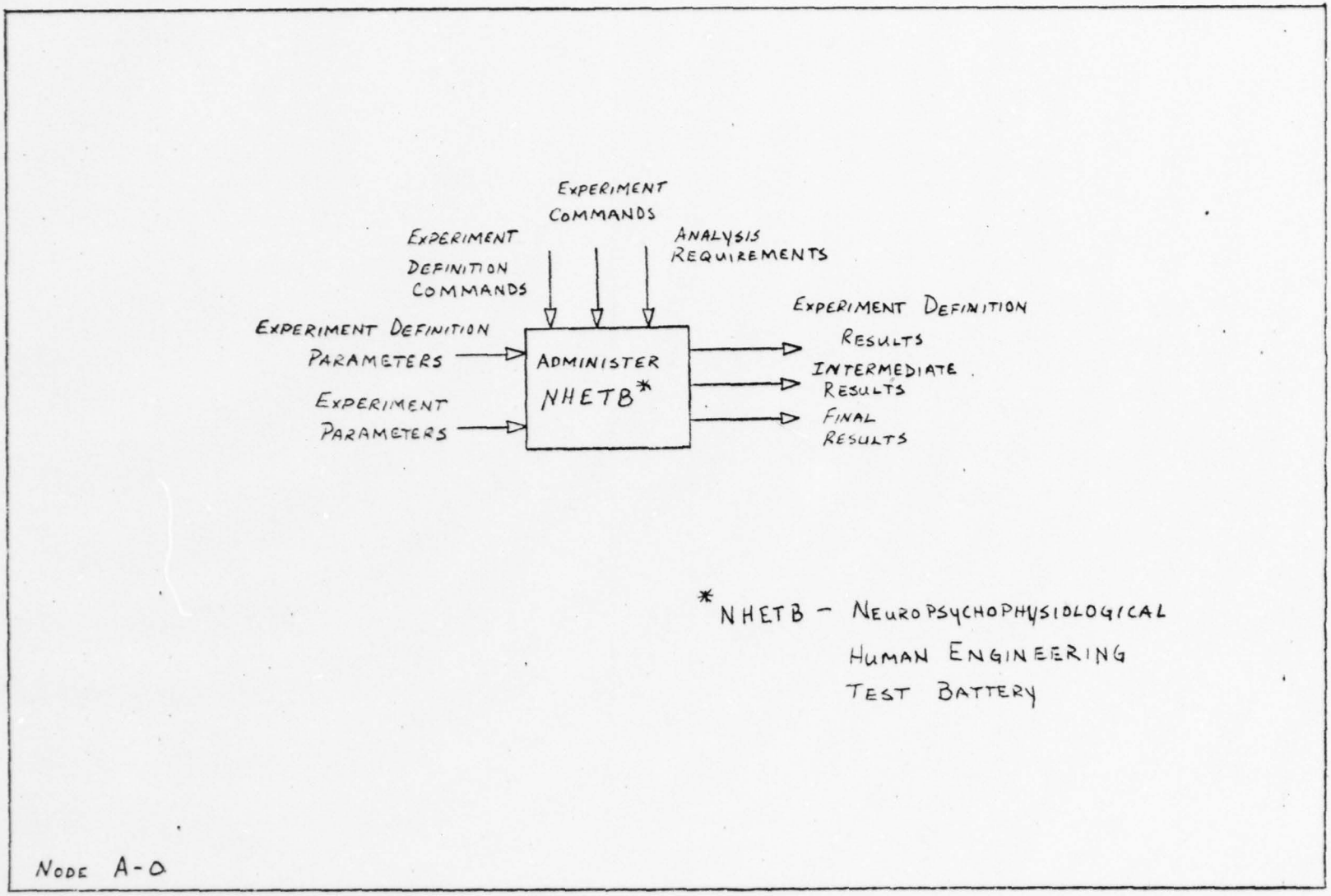

Figure 2. Administer Neuropsychophysiological Human Engineering Test Battery

Administer Neuropsychophysiological Human Engineering Test Battery (A-0)

Node A-0, Figure 2 establishes the context of the Neuropsychophysiological Human Engineering Test Battery. The purpose of this model is to define the overall system requirements. While the model has been developed from the point of view of the system designer, it has also taken into account user considerations as set forth in Appendix A of this paper.

The purpose of this system is to collect and analyze electrophysiological data from human subjects. Towards this end the controlling commands, experiment definition commands (C1), experiment commands (C2), and analysis commands (C3), are used to govern the overall operation of the system. Associated with these commands are the input parameters, experiment definition parameters (I1) and experiment parameters (I2), which are used to further define operations indicated by the controlling commands. In response to the above commands and their associated input parameters there will be outputs produced at various stages of the experimental procedure. These outputs are: experiment definition results (O1), intermediate results (O2), and final results (O3).

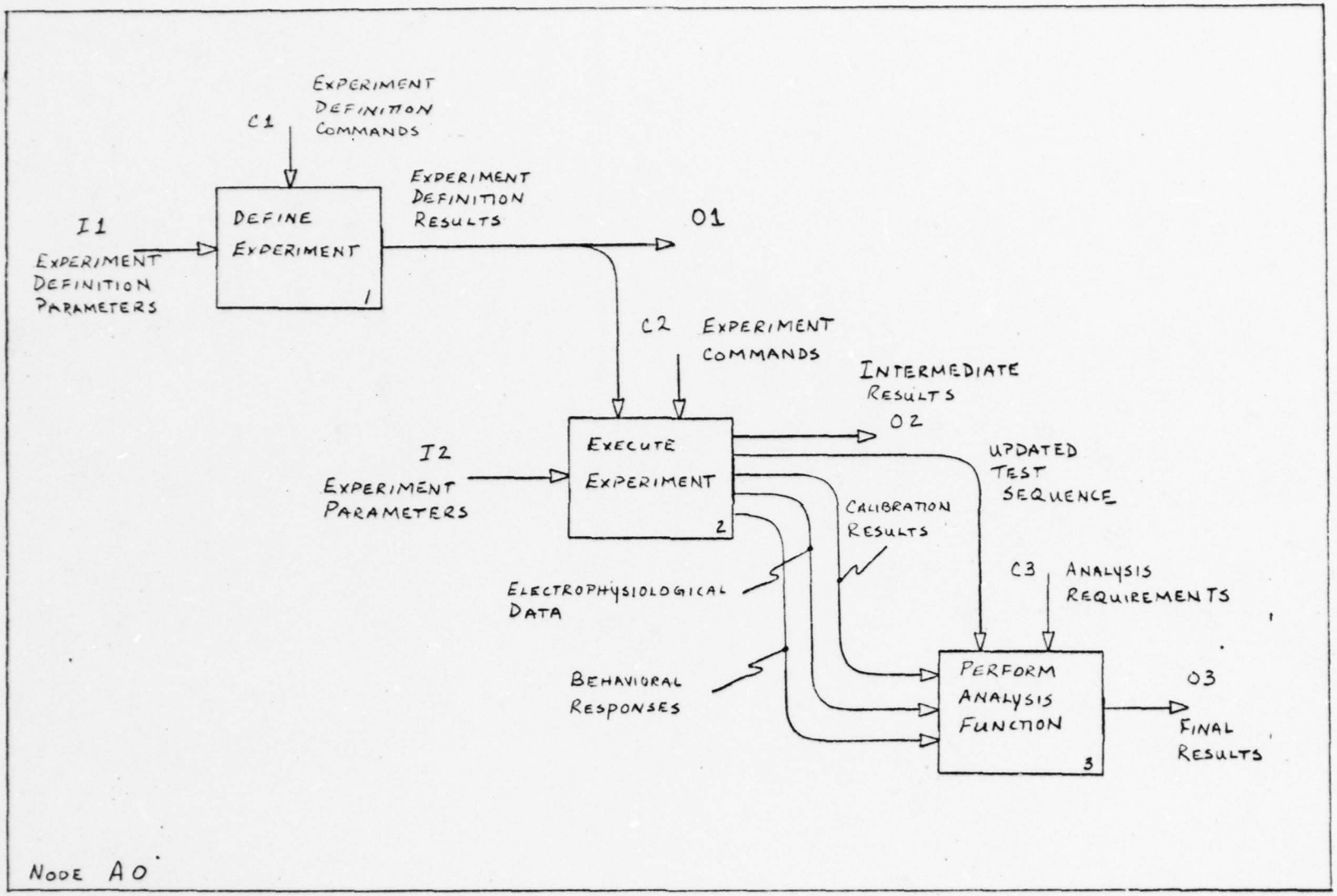

Figure 3. Administer Neuropsychophysiological Human Engineering Test Battery

Administer Neuropsychophysiological Human Engineering Test Battery (A0)

Node A0, Figure 3, shows the decomposition of the A-0 node into three basic modes of operation: define experiment (1), execute experiment (2), and perform analysis function (3).

In the define experiment mode (1), the experiment definition commands (1C1) and the experiment definition parameters (1I1) combine to define the required tests and their sequencing. The output, experiment definition results (101), represents test sequencing information that is developed during the define experiment mode (1).

The execute experiment mode (2) accepts the test sequencing information (2C1) and experiment commands (2C2) and processes the experiment parameters (2I1) to produce the electrophysiological results (205), behavioral responses (204), calibration results (203), updated test sequence (202), and intermediate results (201). The intermediate results (201) are used to monitor experiment progress and have an impact on the course of the experiment (2C3) by introducing changes to the test sequence (2C1) that controls the experiment.

The perform analysis function mode (3) accepts the calibration results (3I1), electrophysiological data (3I2), and behavioral responses (3I3) produced in the execute experiment mode and performs a complete analysis on those inputs. Analysis is constrained by the analysis commands (3C1) which represent the analysis requirements of the experiment and the updated test sequence (3C1) which represents the test sequence and modifications

to the test sequence. The final results (301) are printed out in the form of a report and also stored in permanent memory.

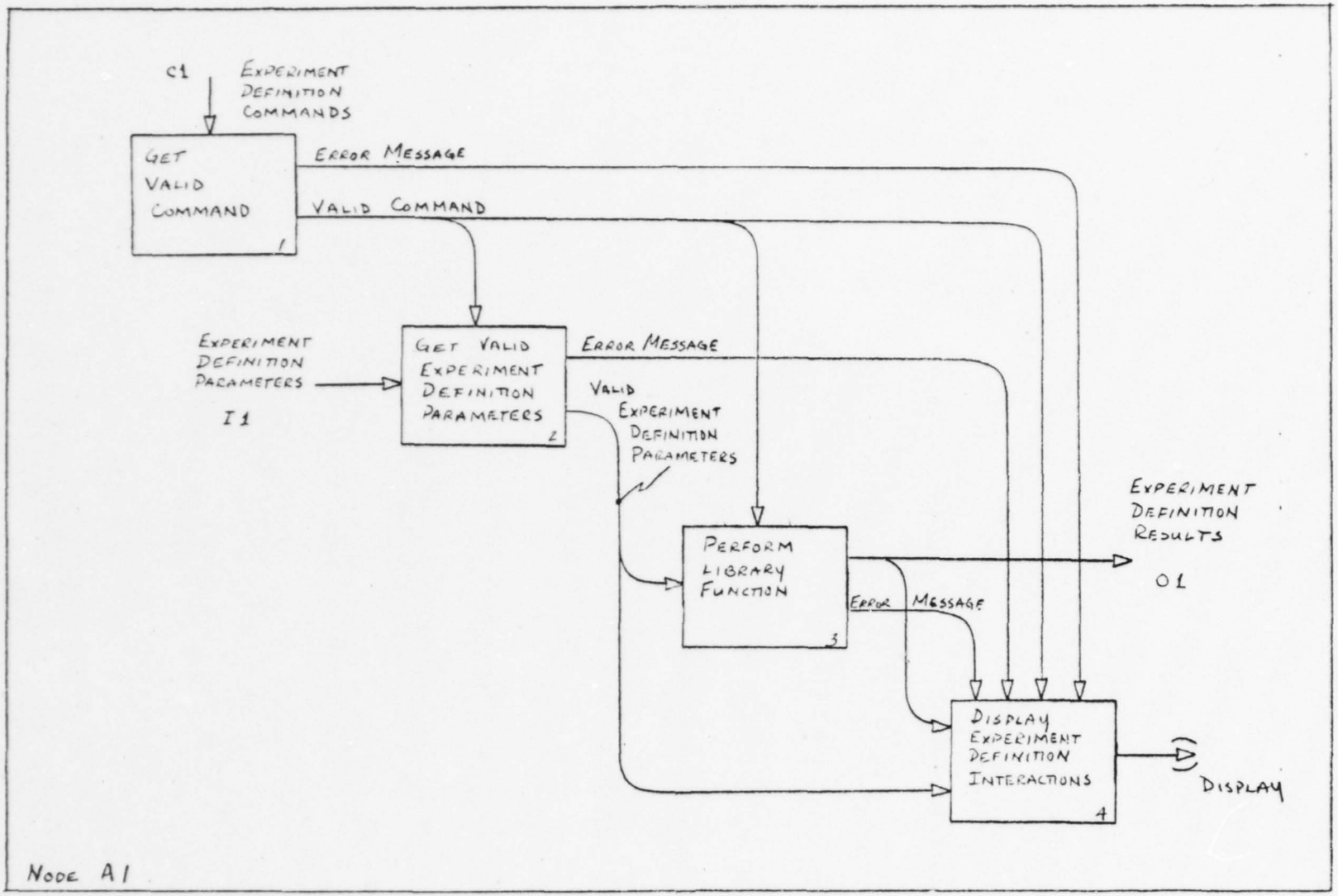

Figure 4. Define Experiment

Define Experiment (A1)

Node A1 is indicated in Figure 4. The function of this module is to define the tests to be administered and the sequencing of those tests. Experiment definition commands (1C1) are examined for validity. Valid commands (102) are generated by the get valid command module (1) and are used to enable the following experiment definition modules. If the initial experiment definition commands are found to be invalid, an error message (101) will be generated instead. This condition will be displayed to the user and will require the command to be re-entered.

The get valid experiment definition parameters module (2) is used to validate experiment definition parameters (2I1) under the control of the valid command (2C1) under consideration. If the experiment definition parameters (2I1) are acceptable the validated experiment definition parameters (202) will be displayed and, at the same time, operated on by the library module (3). Invalid experiment definition parameters cause an error message (201) to be displayed and the experiment definition parameters must be re-entered.

The perform library function module (3) is used to maintain the test library and the test sequence library. Interactions with these libraries take place by entering valid commands (3C1) and valid experiment definition parameters (3I1). Experiment definition results (301) are displayed to the user to indicate the nature of the library transaction that has occurred. Experiment definition results (301) are also passed on to later stages of the model when required. Should a library transaction not be completed

for some reason an error message (302) will be generated to indicate the nature of the error.

The display experiment definition interactions module (4), as alluded to in the above paragraphs, displays the results of interactions with preceding modules. Command (4C4), parameter (4C2), and library (4C1) errors are used to indicate invalid transactions so that the user may take corrective action by re-initiating the transaction. Valid experiment definition parameters (4I2) and experiment definition results (4I1) are displayed subject to the constraints imposed by valid commands (4C3). The display (404) is used to indicate the presentation of the above information to the user. Since this display (401) has no direct input on the following modes of operation it is not carried through in higher level modules as is indicated by the parentheses around the arrow head.

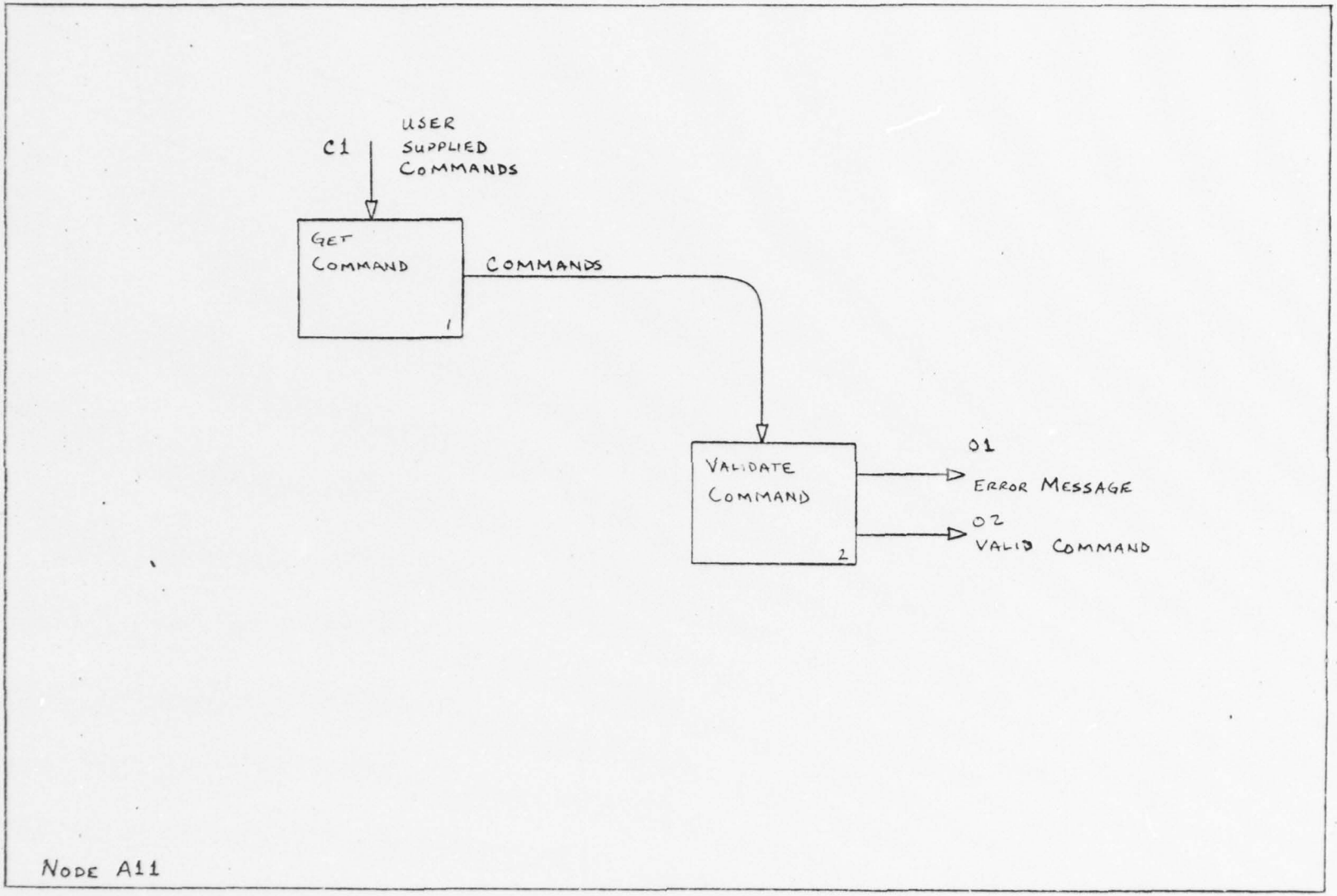

Figure 5. Get Valid Command

Get Valid Command (A11)

Get valid command, node A11 is shown in Figure 5. The commands involved in this module are the Test Library, Test Sequence Library and End Experiment Definition commands and associated subcommands. For a further explanation of these commands see Appendix A.

In the get command module (1), commands (101) are obtained from the user (1C1) and passed on to a validating module (2). This module (2) then examines the commands (2C1) to determine their validity. If the commands (2C1) are acceptable, a validated command is generated (202). If the command (2C1) is found to be in error, the command is rejected and an error message (201) is generated instead.

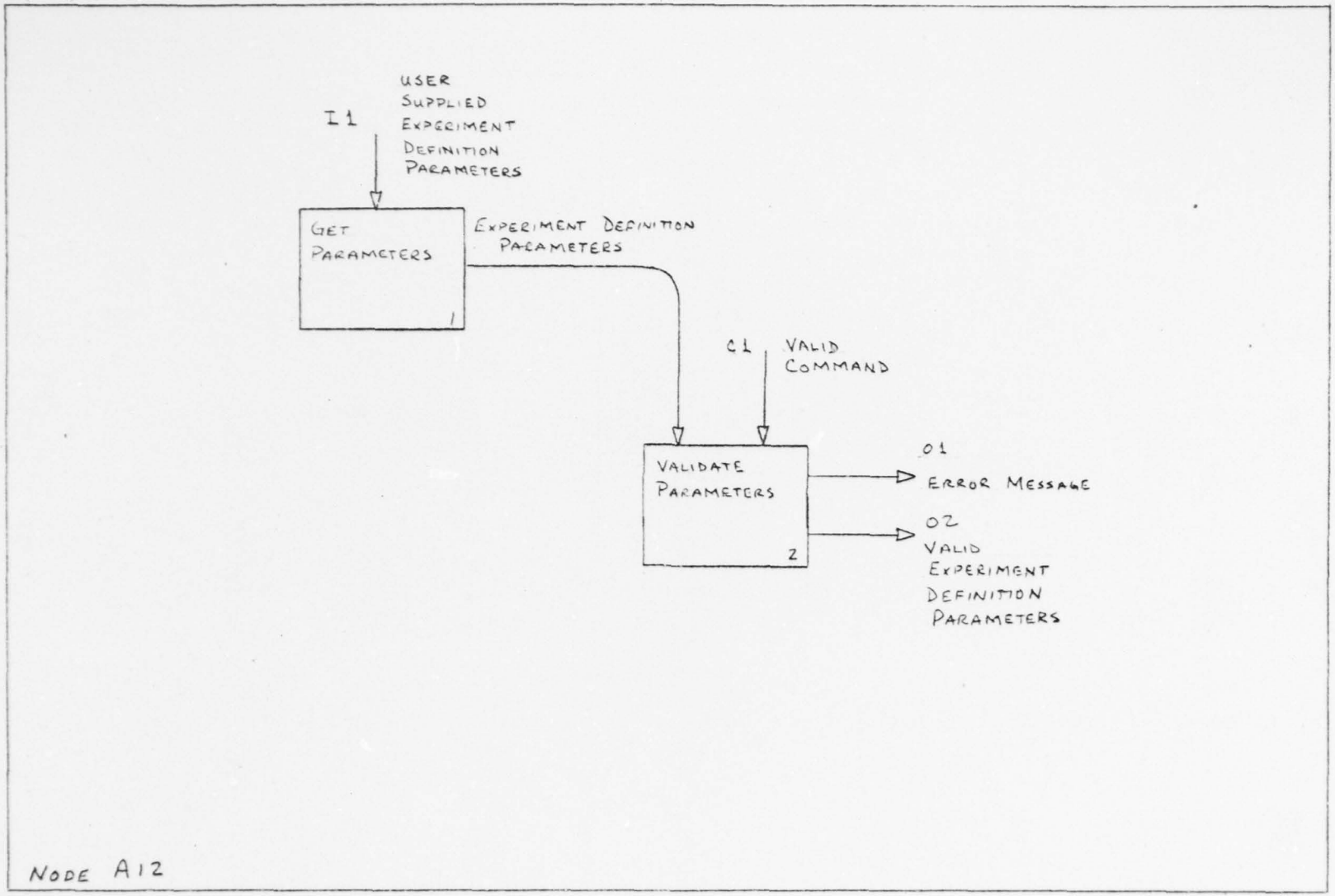

Figure 6. Get Valid Experiment Definition Parameters

Get Valid Experiment Definition Parameters (A12)

The validation of experiment definition parameters in node A12 is presented in Figure 6. Associated with the various commands that were validated in node A11 are the experiment definition parameters that comprise the information being processed under that particular command. For example, in defining a specific test, the user may wish to define the stimuli to be presented to the subject. In order to accomplish this task, the user would enter the Stimuli command. This command would then be followed by the various characteristics (i.e., parameters) of the stimuli involved such as: stimulus name, type, intensity, contrast, focus, frequency, etc. A more detailed explanation of the interaction between commands and parameters is presented in Appendix A.

In the get parameters module (1), experiment definition parameters (101) are obtained from the user (1C1) and passed on to the validating module (2). This module (2) then examines the parameters (2C1) under the additional constraint of previously validated commands (2C2). If these parameters (2C1) are allowable under the particular command (2C2), validated parameters are then generated (202). If the parameters (2C1) are found to be in error, the parameters are rejected and an error message is generated instead.

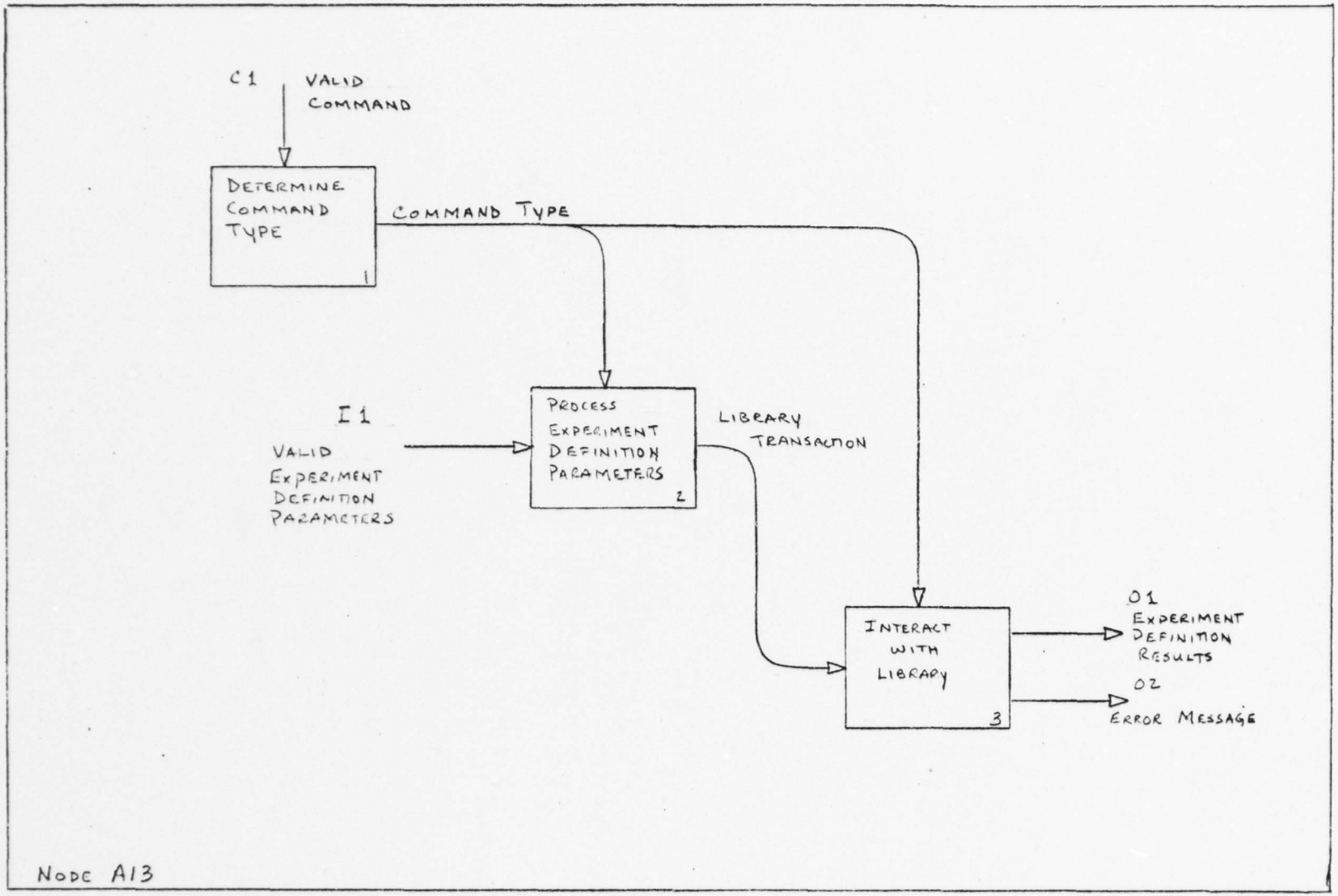

Figure 7. Perform Library Function

Perform Library Function (A13)

The library interactions of node A13 are shown in Figure 7.

Once commands have been validated (1C1) they will be examined (1) to determine command type (101), i.e., what type of library transaction is being requested. Command type (2C1) will then be used to constrain the processing of experiment definition parameters (2). Under this constraint (2C1) validated experiment definition parameters are formated in accordance with the requested operation and the final library transaction (201) is generated. Interactions with the library (3) occur when a command type (3C1) and its associated library transaction (3I1) are received. If for some reason the requested operation is not performed an error message (302) will be generated indicating that the transaction was not successful. Otherwise, the results of the transaction will be output to a display module (A14) or transferred to the execute experiment mode (A2).

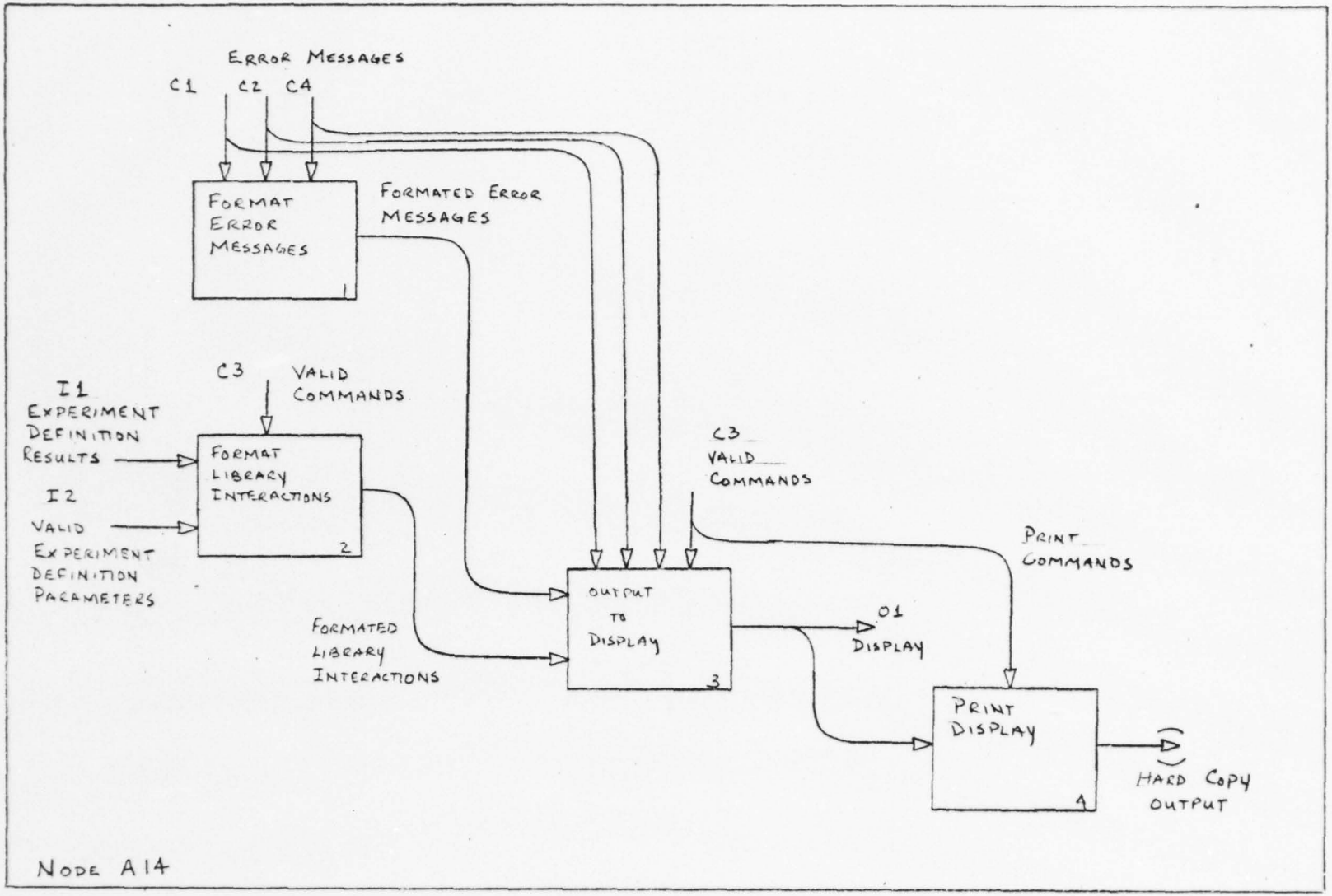

Figure 8. Display Experiment Definition Interactions

Display Experiment Definition Interactions (A14)

Figure 8 shows the procedure required to perform the display experiment definition interactions of node A14.

Error messages (1C1), (1C2), and (1C4) are formated (101). In addition experiment definition results (2I1) and validated experiment definition parameters (2I2) are formated (201) in accordance with the requirements imposed by validated commands (2C1). These formated results (3I1) and (3I2) are then displayed (301) according to the constraints of either error messages received (3C1), (3C2), (3C4) or the validated commands (3C3) received. Once the display has been generated (4I1) a command (4C1) to print out a hard copy (401) of the display may be given. The parentheses around the hard copy output indicate that this output does not appear in higher levels of the model. The reason for invoking this SADT convention is that the hard copy output is localized in this node and has no direct bearing on the rest of the model.

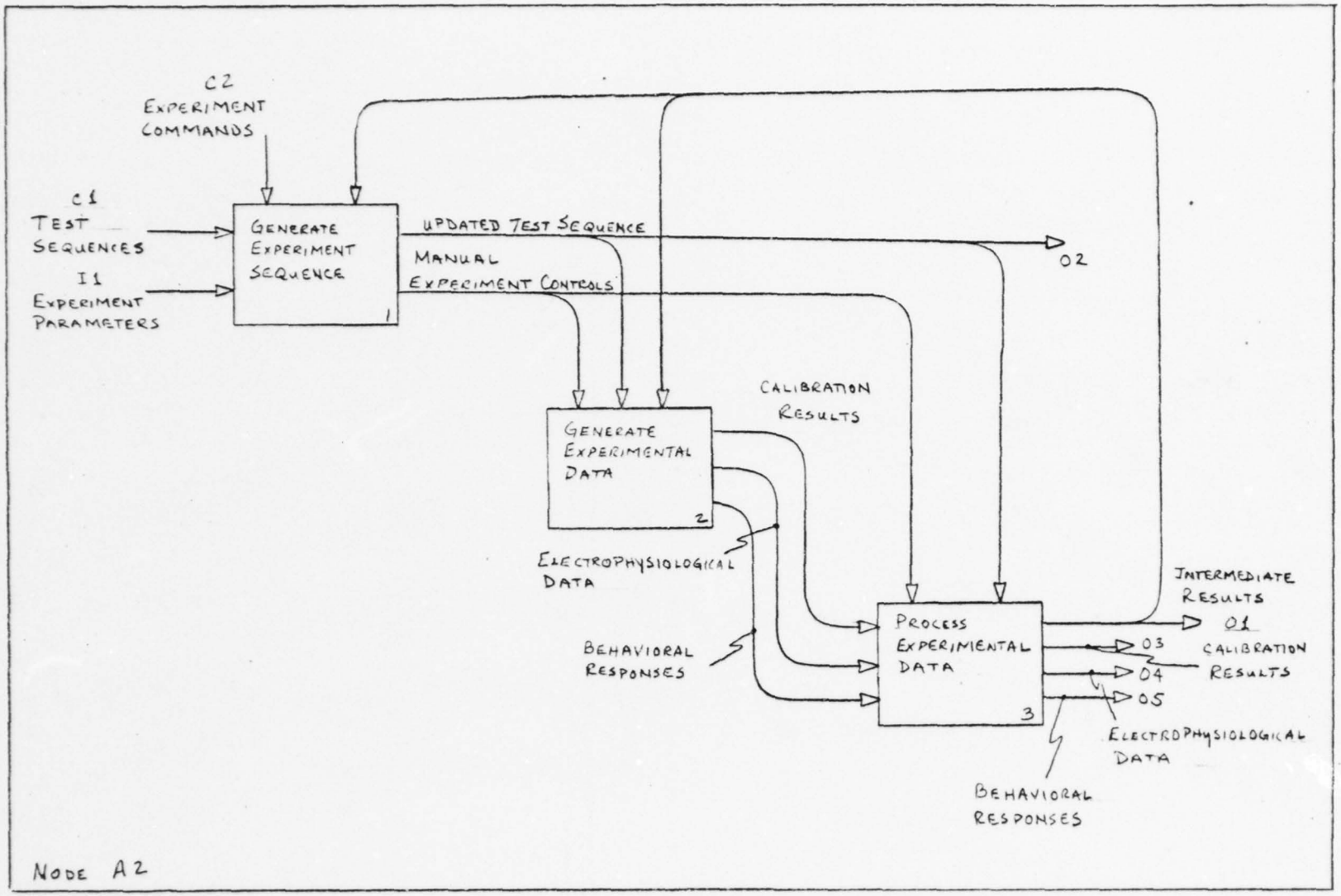

Figure 9. Execute Experiment

Execute Experiment (A2)

The execute experiment mode is shown in node A2, Figure 9. Generally speaking, the execute experiment function is concerned with all operations required during an experimental session. Included in these operations is the application of electrodes to the subject and initial calibration procedures as well as experimental data collection and follow-up calibrations.

Controls for the experiment (1) are generated in response to experiment commands (1C1) and associated experiment parameters (1I2). Operation in this mode (A2) begins with the fetching of a test sequence (1I1). Further interaction with this module (1) through the commands (1C1) and associated parameters (1I2) produces manually initiated experiment controls (103) and the updated test sequence (102) which reflects changes in the test sequence during the course of the actual experiment. Whereas the manually initiated controls (103) represent direct user interventions, the updated test sequence (102) represents computer initiated controls. It should also be noted that the updated test sequence (102) is only altered for the particular experiment being run - it remains unchanged in its permanent library location. This measure is required so that analysis will be able to address the tests that are actually administered. It is assumed that such changes in the test sequence are only temporary. Any permanent changes to the library must be made in the define experiment mode (A1). These temporary changes occur in response to the intermediate results generated (301). These intermediate results (301) represent the progress of the experiment as observed by the experimenter or detected by

the computer system. The intermediate results (3O1) can then serve as a basis for initiating user or computer driven changes to the updated test sequence (102) or the manual experiment controls (103).

In the generate experimental data module (2) the manual experiment controls (2C1), updated test sequence (2C2), and the intermediate results (2C3) constrain the performance of the experiment. As a result of performing the experiment calibration results (2O1), electrophysiological data (202) and behavioral responses (203) are generated.

The calibration results (3I1), electrophysiological results (3I2), and behavioral responses (3I3) are processed (3) under the constraints of the manually initiated controls (3C1) and the updated test sequence (3C2) to produce the intermediate results (3O1). As mentioned previously, these intermediate results (3O1) are used to provide feedback to the experimenter concerning the progress of the experiment and to initiate changes in the normal course of the experiment. During this processing (3) the input data are stored in permanent memory. The data are made available to later modules by referencing the updated test sequence (3C2). This information is represented by calibration results (302), electrophysiological data (303), and behavioral responses (304).

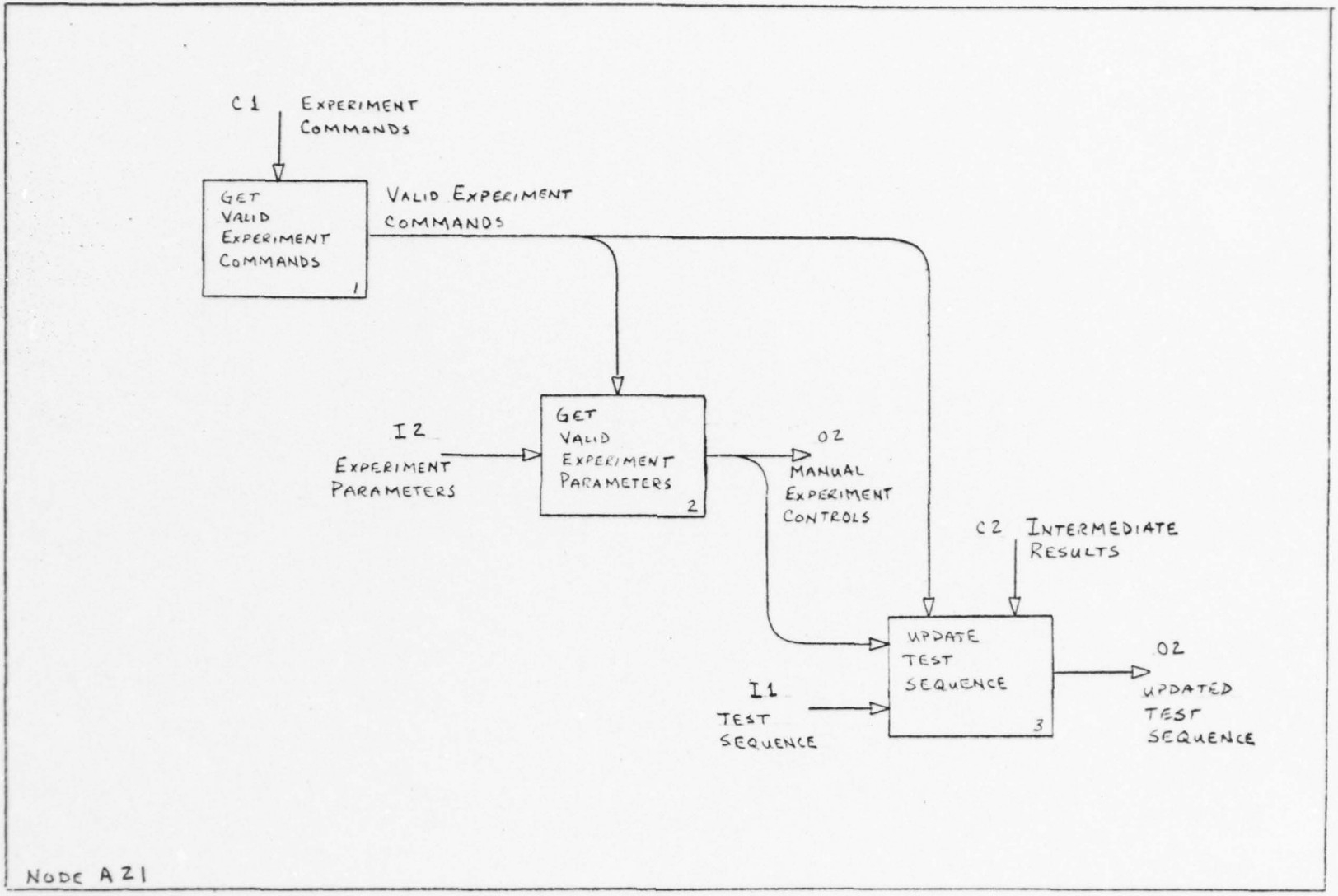

Figure 10. Generate Experiment Sequence

Generate Experiment Sequence (A21)

The decomposition of the generate experiment sequence node, A21, is shown in Figure 10.

Experiment commands (1C1) are submitted by the user. These commands are then validated (1) and the resulting validated commands (1O1) are used to constrain the remainder of the control experiment module (A21).

Under the constraint of the above validated commands (2C1), experiment parameters (2I1) are obtained and validated (2). In response to these commands (2C1) and parameters (2I1) a manual experiment control (2O1) is then used to perform its assigned operation and to update the test sequence to reflect that operation.

The test sequence (3I2) for the experiment under consideration is obtained by the update test sequence module (3). Throughout the remainder of the execute experiment mode (A2) valid experiment commands (3C1), intermediate results (3C2), and manual experiment controls (3I1) combine to update the original test sequence (3I2). The results of these changes are represented by the updated test sequence output (3O1).

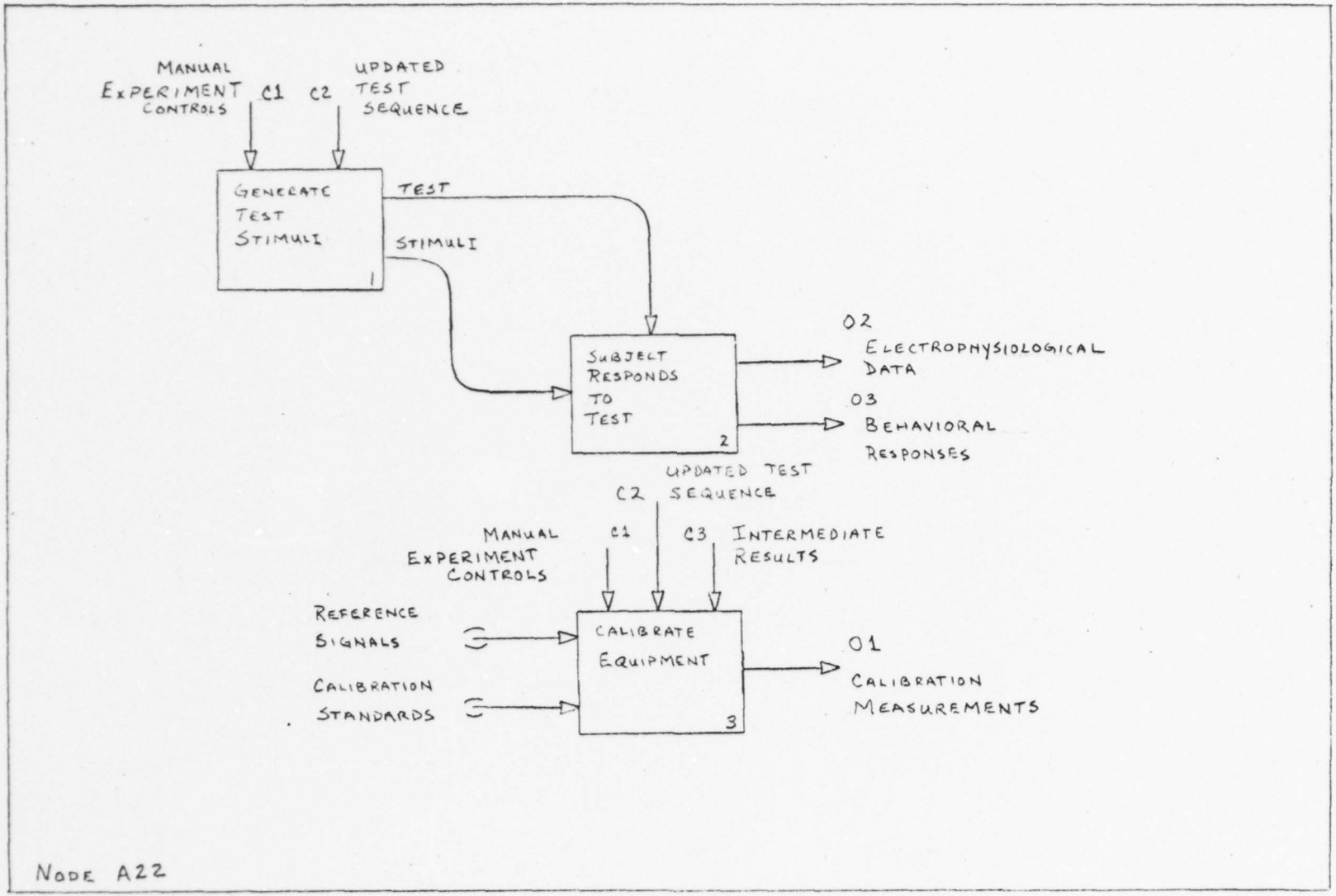

Figure 11. Generate Experimental Data

Generate Experimental Data (A22)

Figure 11 illustrates the functions of the generate experimental data module, node A22.

The manual experiment controls (1C1) and the updated test sequence (1C2) are used to generate (1) the individual tests (101) and their associated stimuli. In response to the various stimuli (2I1) the subject responds (2) according to the constraints imposed by the particular test being administered. These subject responses are in the form of electrophysiological data (201) (e.g., electroencephalographic waveforms, etc.) and behavioral responses (202) (e.g., outputs from a response key, etc.).

In addition to the above data, there are data (301) generated from the calibration (3) of the system equipment at various stages of the experiment. These calibration measurements may be initiated manually (3C1), at specific points specified by the updated test sequence (3C2), or when the intermediate results (3C3) suggest re-calibration. The calibration measurements (301) are taken relative to reference signals (3I1) of known value and calibration standards (3I2) that specify acceptable ranges for the calibration measurements (301). Should calibration measurements (301) fall outside of acceptable ranges the experimenter will have to make a decision to either suspend the experiment while equipment is adjusted or to proceed with the experiment under the degraded conditions.

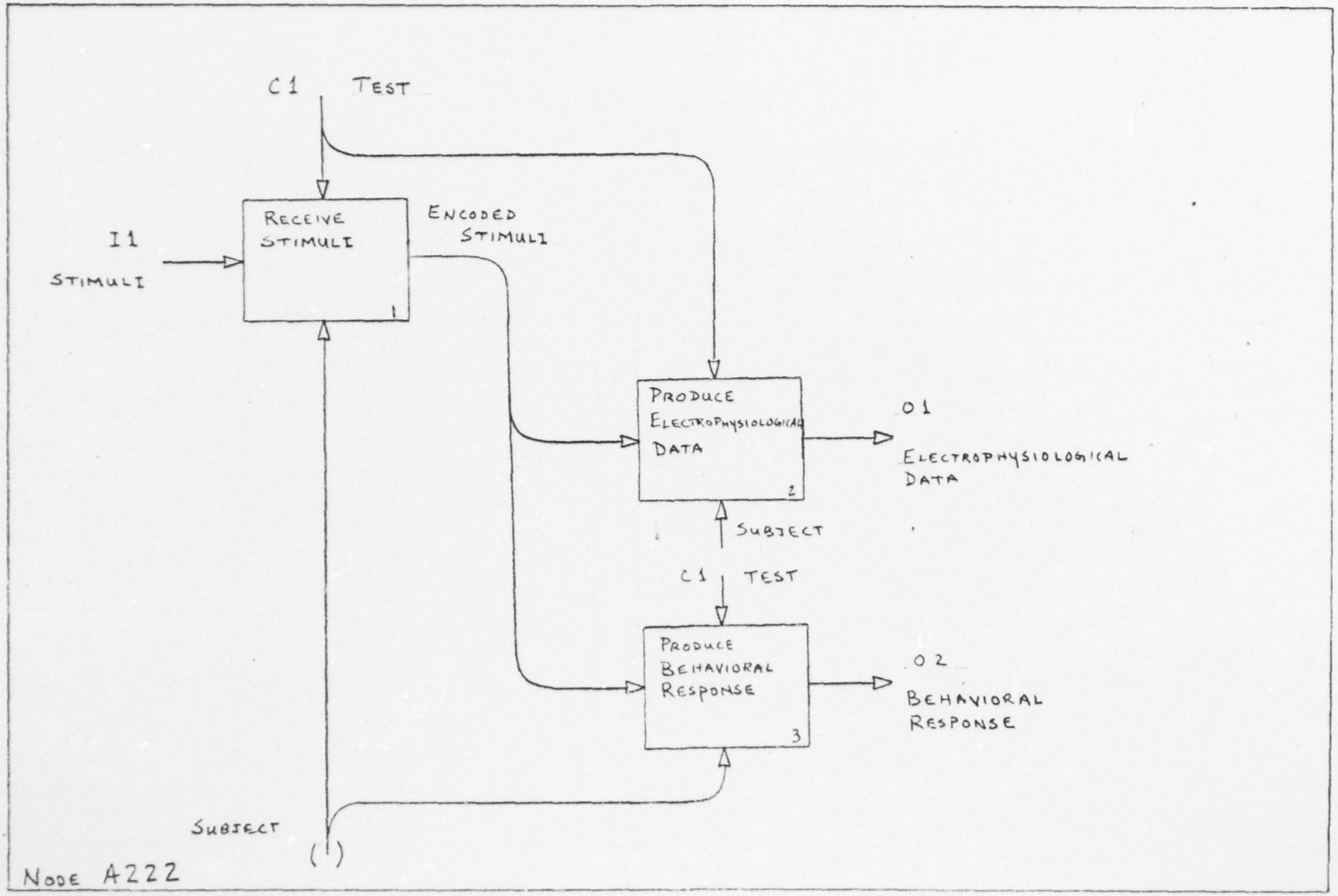

Figure 12. Subject Responds to Test

Subject Responds to Test (A222)

Figure 12 is used to illustrate the subject responds to test module, node A222. The purpose of this module is to model the behavior of the subject during the experiment. The specific test being administered (C1) constrains all functions performed by the subject. In addition, the subject mechanism arrows (1M1), (2M1), and (3M1) are shown to emphasize the fact that the human subject is the operator in this module (A222).

The subject receives (1) the test stimuli (1I1) through his sensory channels. These stimuli (1I1) are then encoded (1O1) into a form that is recognizable to the subject. As the subject processes these encoded stimuli (2I1), (3I1) he will produce (2) the appropriate electrophysiological data (2O1), e.g., electroencephalogram, etc. Additionally, he may also produce (3) a behavioral response, e.g., depress a response key.

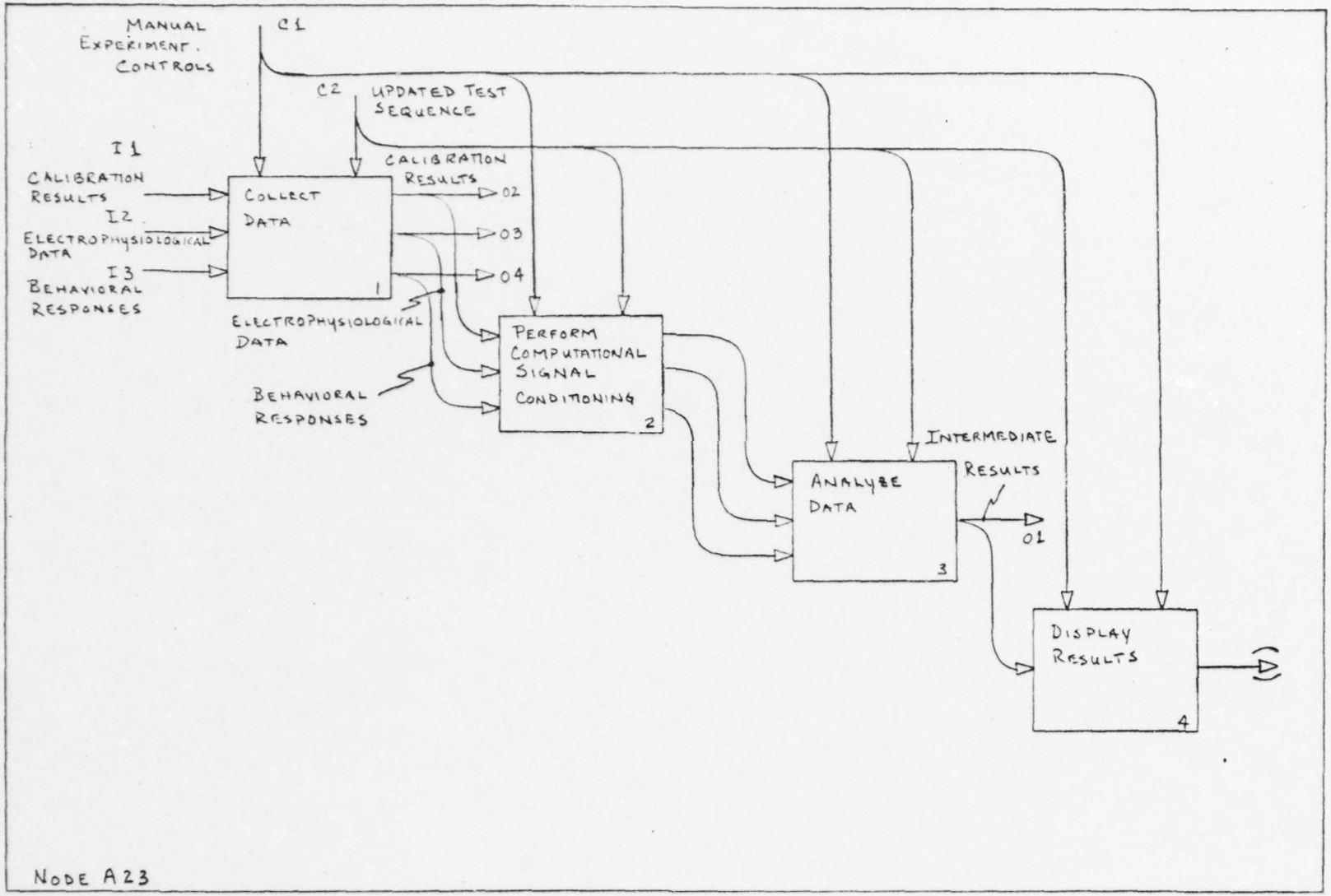

Figure 13. Process Experimental Data

Process Experimental Data (A23)

The procedure for processing experimental data is shown in node A23, Figure 13. All modules in this procedure are under the control of the manual experiment controls (C1) and the updated test sequence (C2).

Experimental data (1I1), (1I2), and (1I3) are collected (1) and made available to succeeding stages of the system (101), (102), and (103). Additional signal conditioning (2) on this data takes place. A preliminary analysis (3) of the data is performed. The results of this analysis (301) are displayed (4) so that the experimenter may monitor the progress of the experiment. These intermediate results (301) are also used to initiate automatic interventions in the test sequence such as artifact rejection, etc.

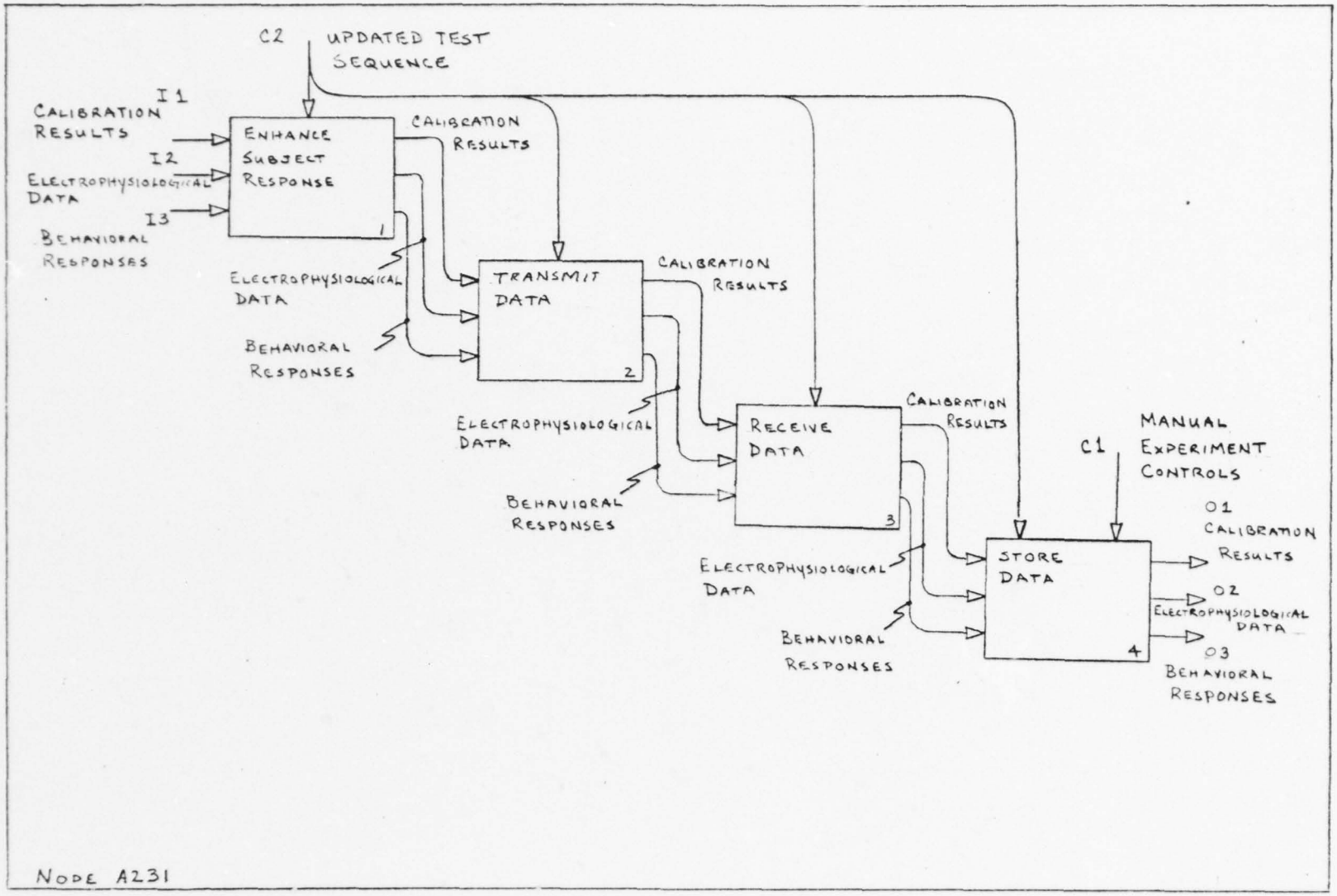

Figure 14. Collect Data

Collect Data (A231)

The functions comprising the collect data module, node A231 are shown in Figure 14.

The enhance subject response module (1) performs such signal enhancements as initial filtering, amplification, etc. Calibration results (II1), electrophysiological data (II2), and behavioral responses (II3) are the data of interest during this process. These data are then transmitted (2). At the main site of the test battery facility, the data are received (3) and converted into its final form before being stored (4). The updated test sequence (C2) is the primary control for the first three modules. In addition to the updated test sequence (4C1), the store data module (4) may be accessed through the manual experimental controls (4C2). These manual references (4C2) represent requests for signal processing not directly associated with the updated test sequence (4C1).

The transmit (2) and receive (3) functions may be very trivial functions in instances where experiments are conducted at the test battery facility. And they may be very complex when they are removed from the main facility, e.g., from a ground based remote terminal or from an aircraft. Both of these situations must be addressed in the final system.

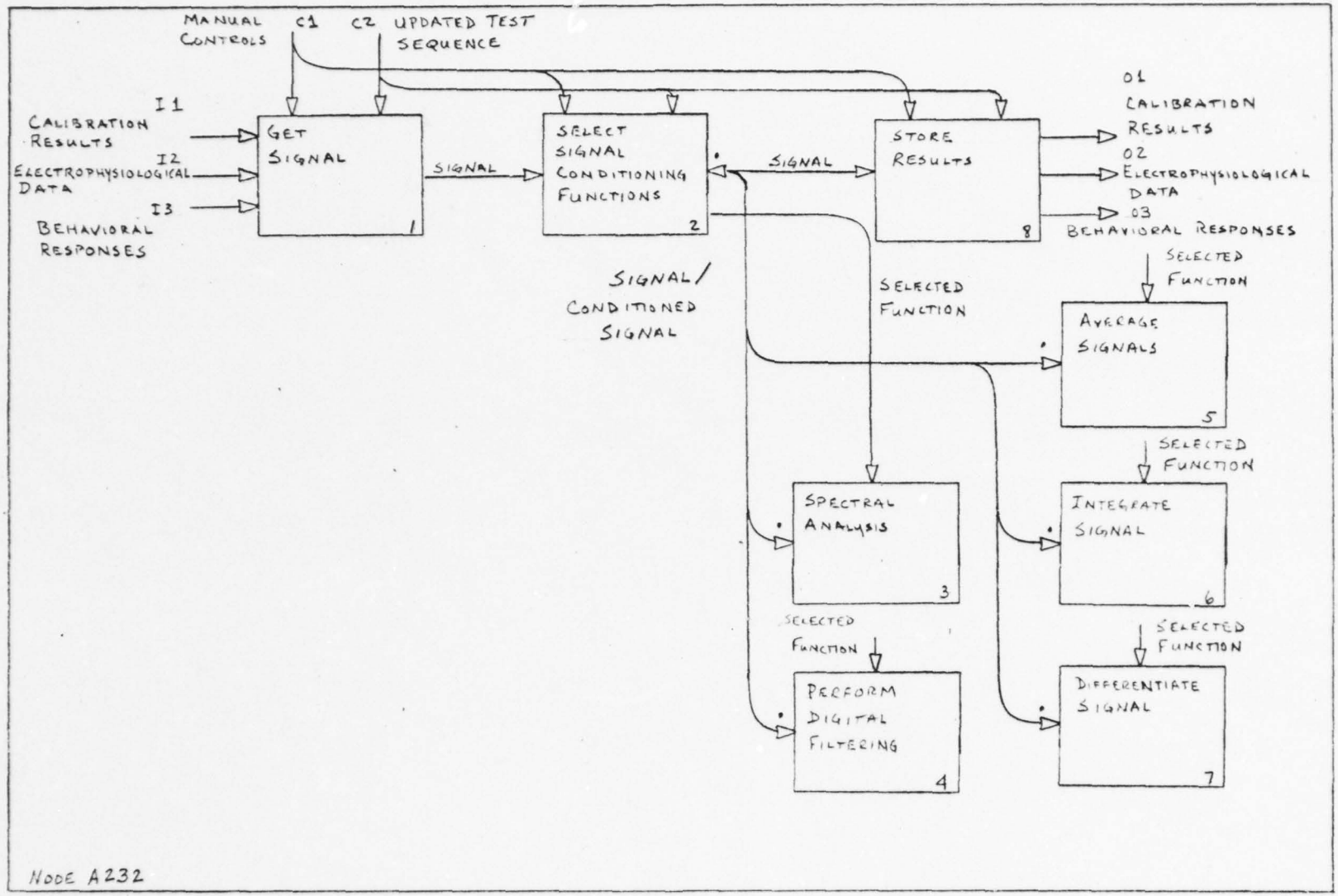

Figure 15. Perform Computational Signal Conditioning

Perform Computational Signal Processing (A232)

The procedure for performing computational signal processing is indicated in node A232, Figure 15.

Manual controls (C1) and the updated test sequence (C2) control the modules in this mode. Selected function (202) is derived from these controls so that they (C1)(C2) indirectly control the various signal conditioning routines.

Calibration results (1I1), electrophysiological data (1I2), and behavioral responses (1I3) are recalled (1) from memory. Signal conditioning functions are selected (2) (there may be more than one of these functions operating on the selected signal), the functions are performed (3 thru 7), and the results of these operations are stored (8) for further processing in the form of calibration results (801), electrophysiological data (802), or behavioral responses (803). The situation may occur where no signal conditioning is desired, e.g., behavioral responses from a response key. In this case data is passed on to storage (8) without any signal conditioning.

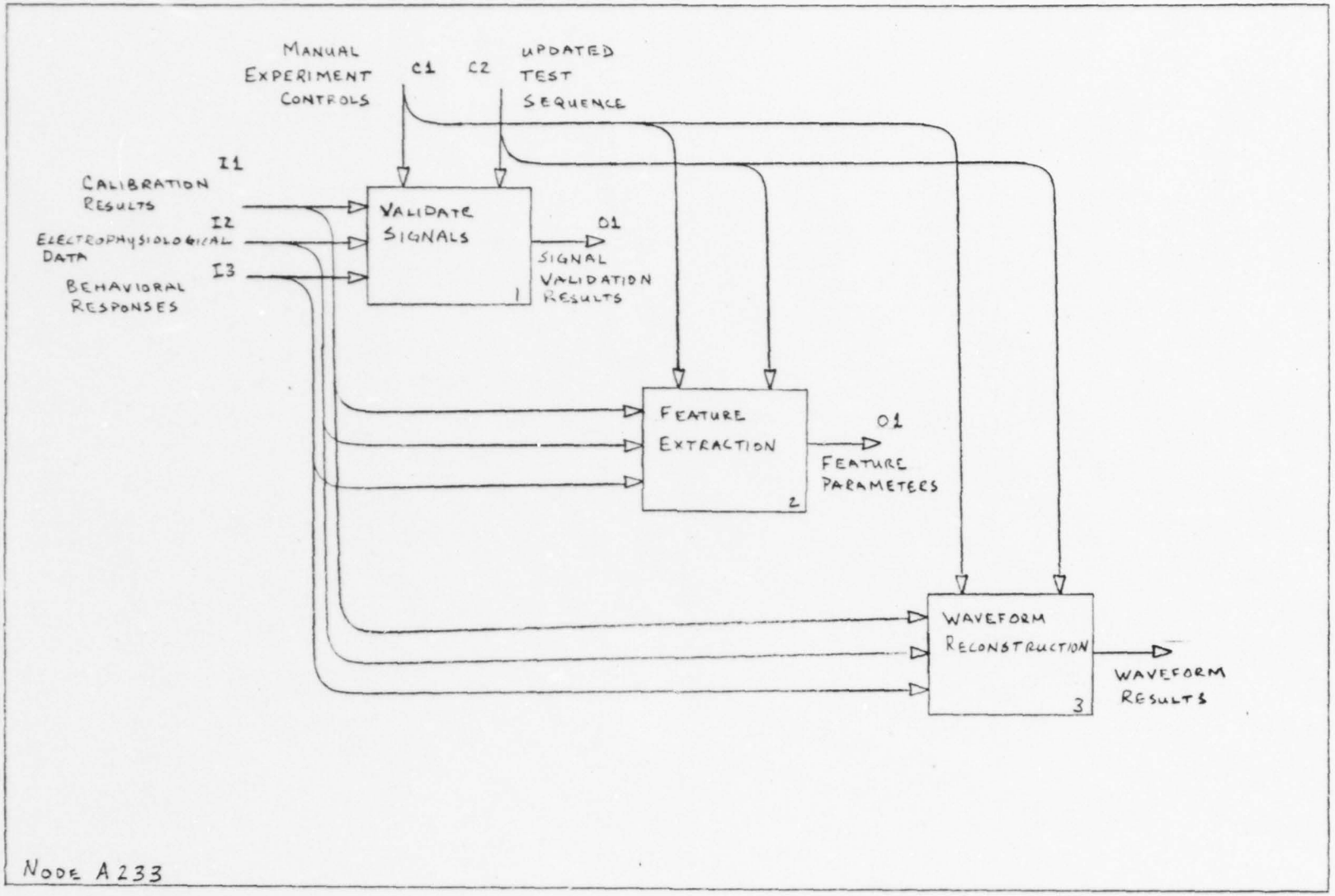

Figure 16. Analyze Data

Analyze Data (A233)

The analysis functions performed on the data during the experiment mode are indicated in node A233, Figure 16.

Under the constraint of both manual experiment controls (C1) and the updated test sequence (C2) the experimental data, calibration results (I1), electrophysiological data (I2), and behavioral responses (I3), are analyzed. The functions performed are validate signals (1), e.g., artifact rejection, feature extraction (2), e.g., identification of response components, and waveform reconstruction. The outputs of these functions are then displayed to provide information on experiment progress.

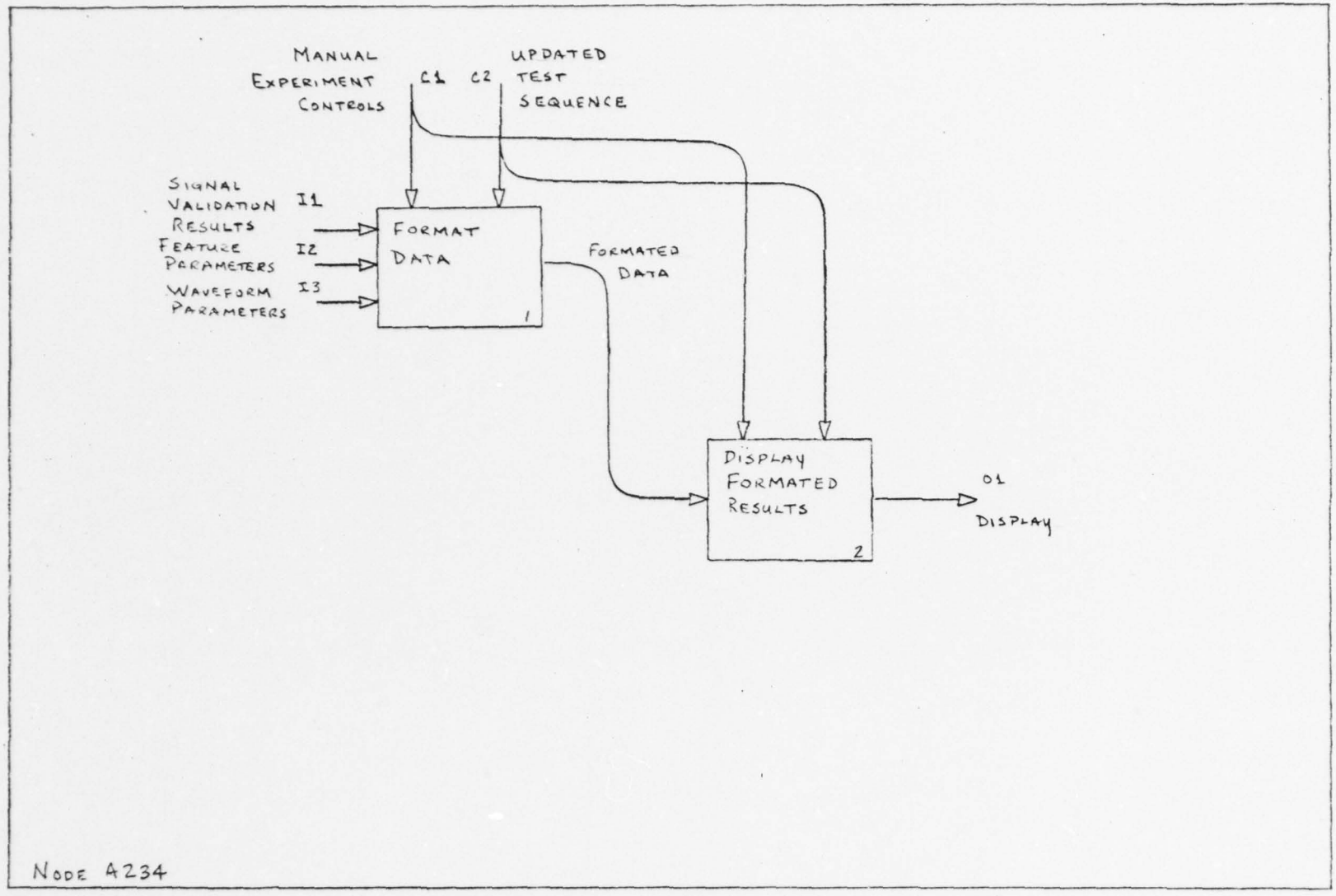

Figure 17. Display Results

Display Results (A234)

The procedure for display results are shown in node A234, Figure 17. The intermediate results produced in the analysis module (A233), signal validation results (1I1), feature parameters (1I2), and waveform parameters (1I3),are formated (1) and then displayed (2) to the experimenter. These functions operate under constraints imposed by manual experiment controls (C1) and the updated test sequence (C2).

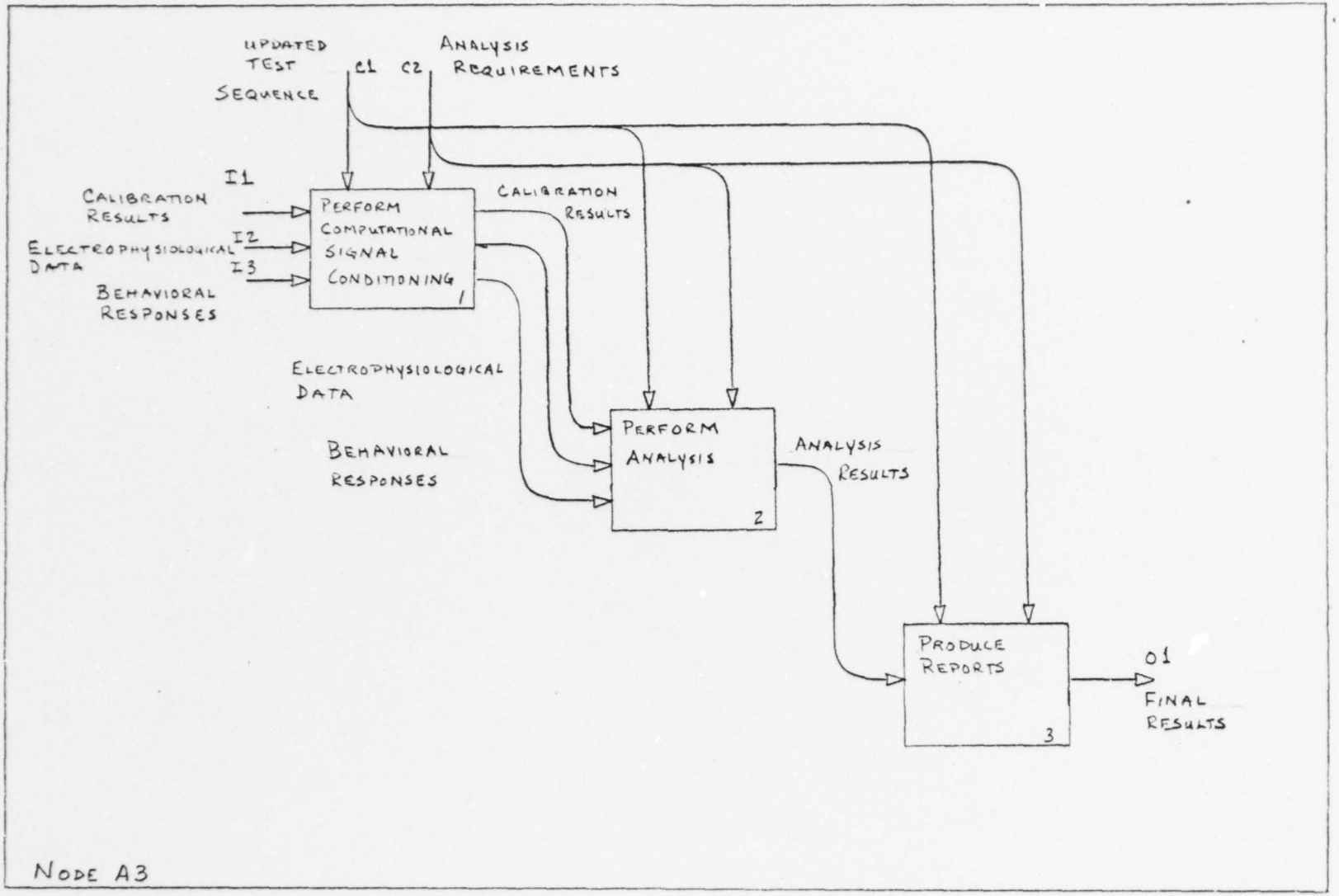

Figure 18. Perform Analysis Function

Perform Analysis Function (A3)

The perform analysis module, node A3, is illustrated in Figure 18.

At the end of the execute experiment mode (A2) the updated test sequence (C1) is passed to the analysis mode (A3) and serves as a constraint for the analyses that take place. In addition, the overall analysis requirements (C2) serves to further constrain the required analyses.

The calibration results (1I1), electrophysiological data (1I2), and behavioral responses (1I3) undergo some computational signal conditioning (1). These data are then analyzed (2) and the analysis results (201) are output (3) in the form of a final report.

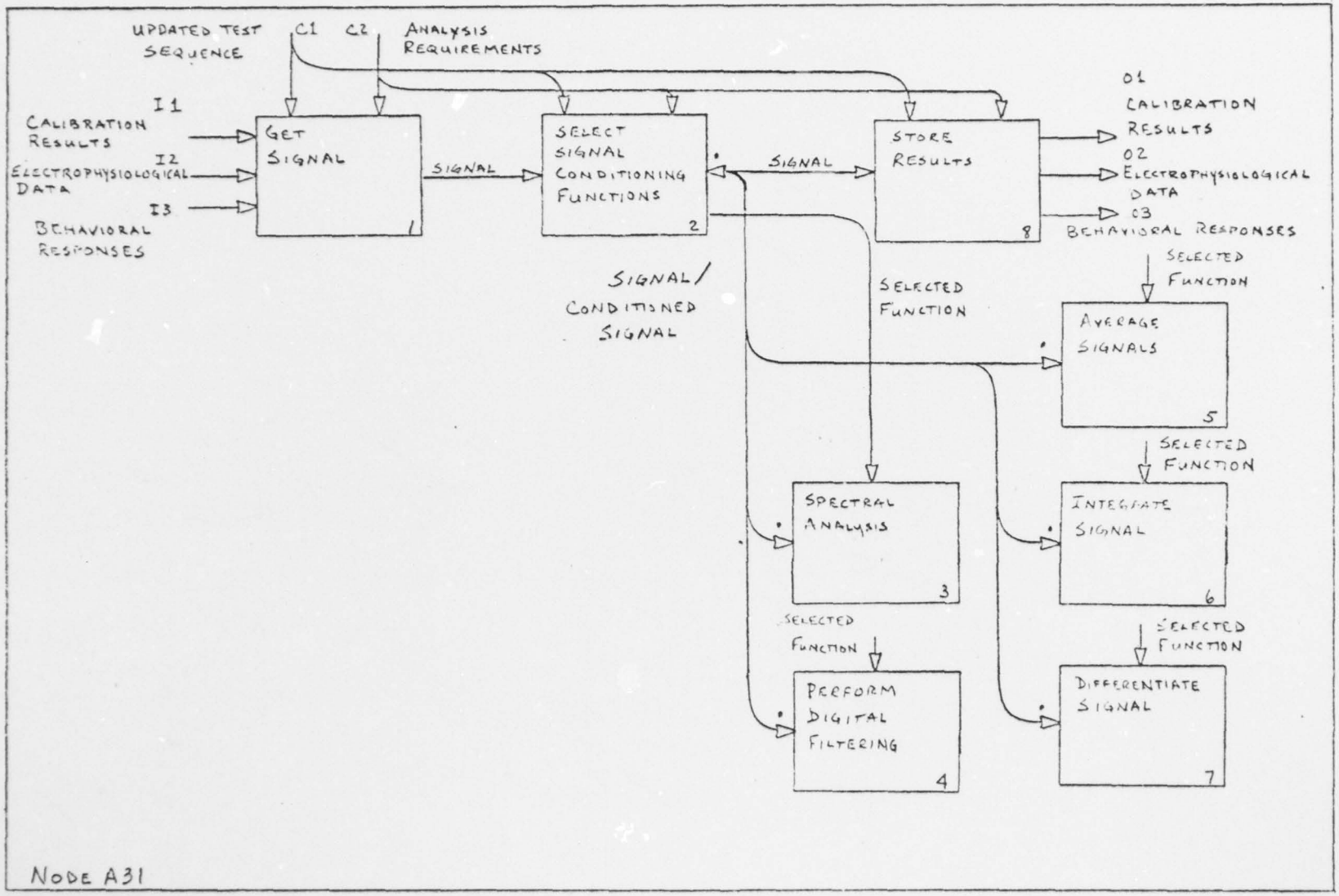

Figure 19. Perform Computational Signal Conditioning

Perform Computational Signal Conditioning (A31)

Perform computational signal conditioning is shown in node A31, Figure 19. The updated test sequence (C1) and the analysis requirements (C2) control the modules of this node. Otherwise this node is identical to the perform computational signal processing done in node A232.

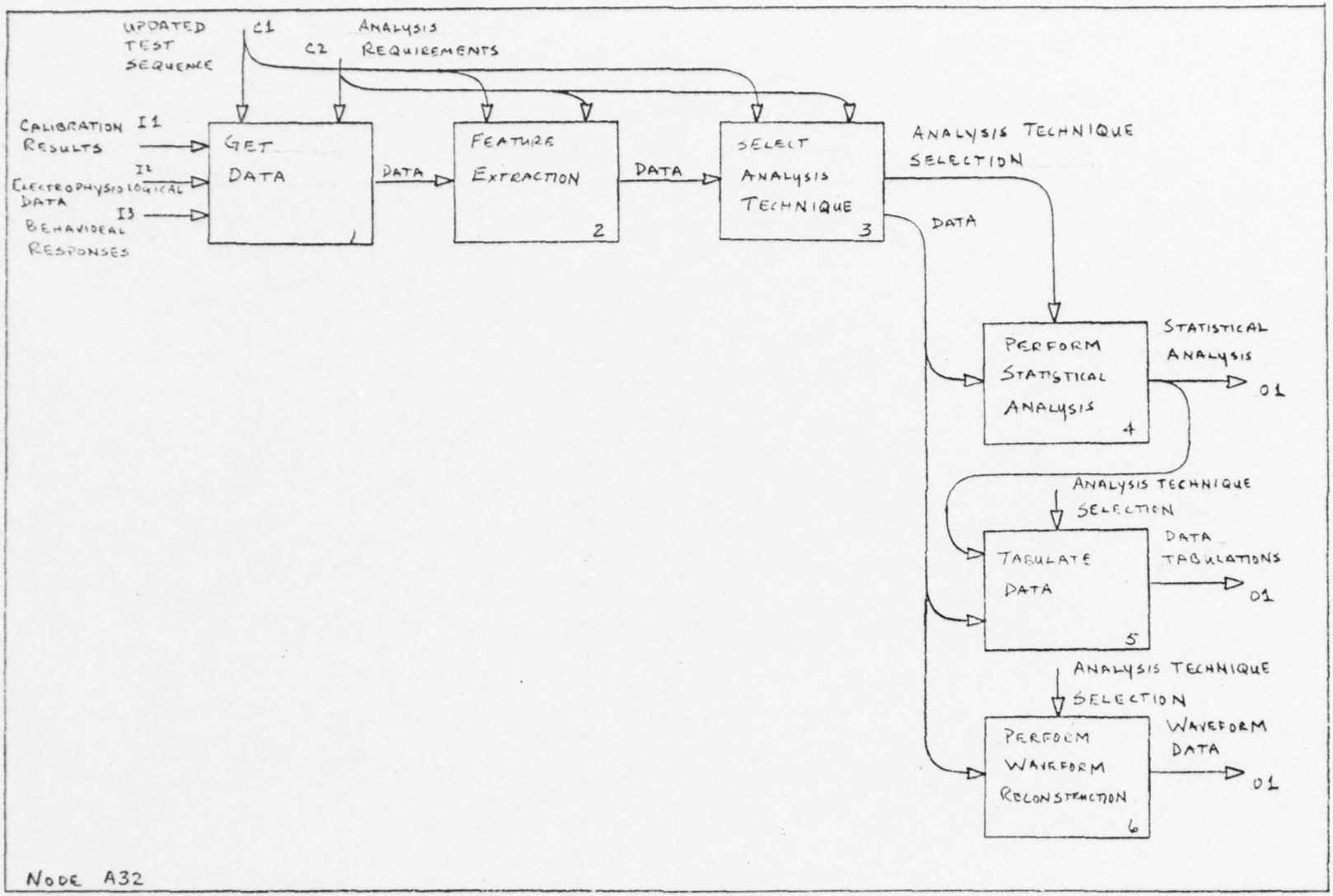

Figure 20. Perform Analysis

Perform Analysis (A32)

Figure 20 indicates the decomposition of the perform analysis function, node A32.

The constraints on this function are the updated test sequence (C1) and the analysis requirements (C2) (the analysis techniques selection (301) is derived from these signals).

Data are acquired (1) from the storage area containing calibration results (1I1), electrophysiological data (1I2), and behavioral results (1I3). Features are extracted (2) from this data (2I1) (features of interest may be a single time measurement of a specific waveform component, the entire waveform, or some other feature specified in the analysis requirements). The desired analysis techniques are accessed (3) resulting in statistical analyses (4) (e.g., analysis of variance, hypothesis testing, regression analysis, etc.), tabulation of data (5) (e.g., tables, histograms, distributions, etc.), and waveform reconstruction (6).

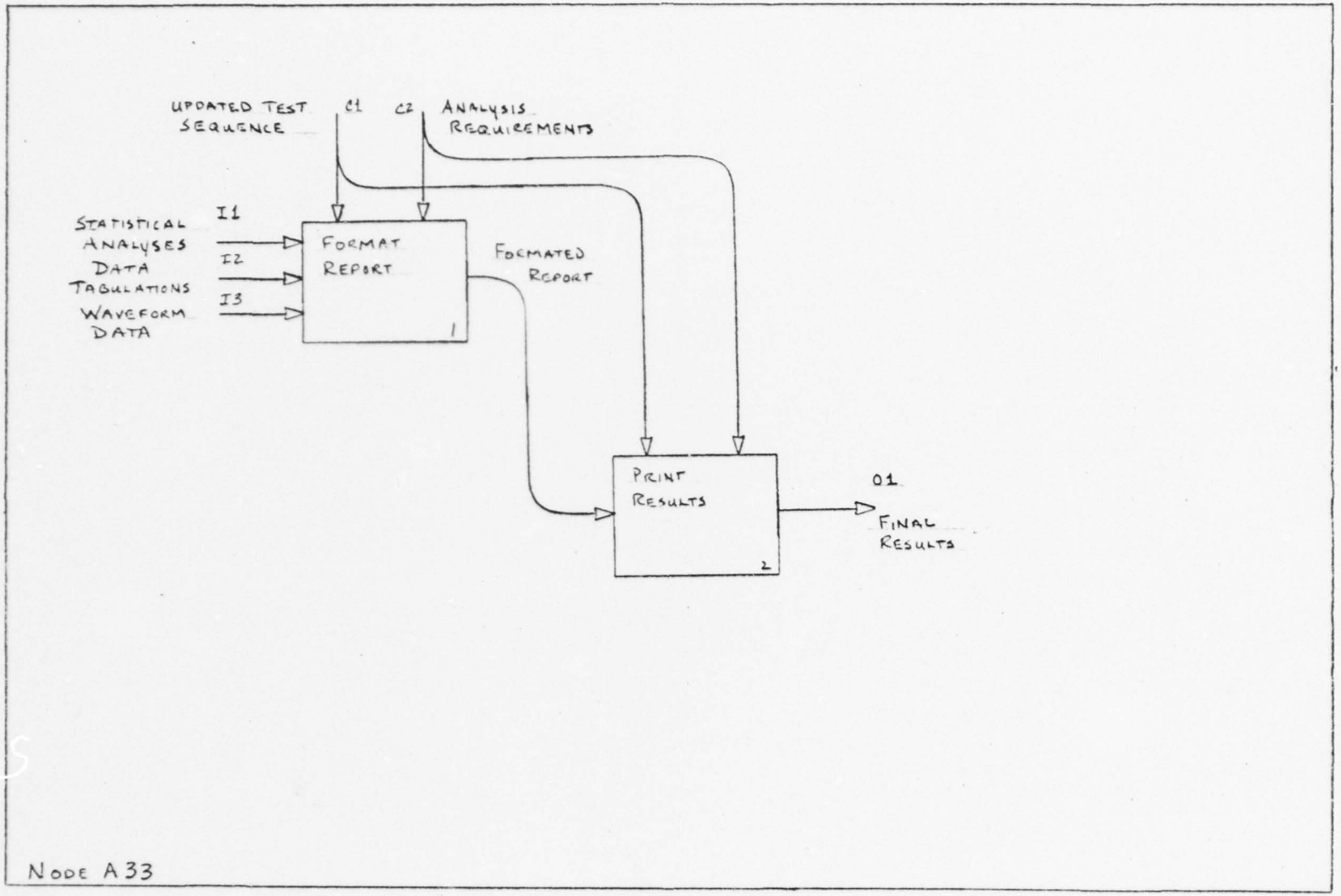

Figure 21. Produce Reports

Produce Reports (A33)

The procedure for generating reports is shown in node A33, Figure 21.

Analysis results (statistical analyses (1I1), data tabulations (1I2), and waveform data (1I3) are formated (1) in accordance with the updated test sequence (1C1) and the analysis requirements (1C2). The resulting formated report (1O1) is then printed out (2).

IV Preliminary Design

The purpose of this chapter is to develop a preliminary design for the Neuropsychophysiological Human Engineering Test Battery presented in this paper. The development of this preliminary design will focus on two points of view. First, the software structure of the system will be discussed and developed. This discussion will be followed by a discussion on the general structure of the required hardware.

Software

Design Structure. In applying SADT the analyst focuses on successively finer detailed levels of the problem. By following this procedure, he can examine aspects of the problem in relative isolation from the total problem and still insure that decisions made at these sublevels are consistent with the overall objectives of the entire system. During the definition of system requirements the application of some degree of "tunnel vision" is appropriate as it allows the analyst to closely scrutinize each aspect of the system. Once the requirements definition has been completed, the next logical step in the life cycle of a system is design. At this point it is instructive to develop a structure chart (explained below) in order to gain an appreciation of the overall software structure implied by the SADT model developed during the requirements definition phase and to identify common functions between various modules defined in the SADT model. Figure 22 shows a partial structure chart to illustrate the design

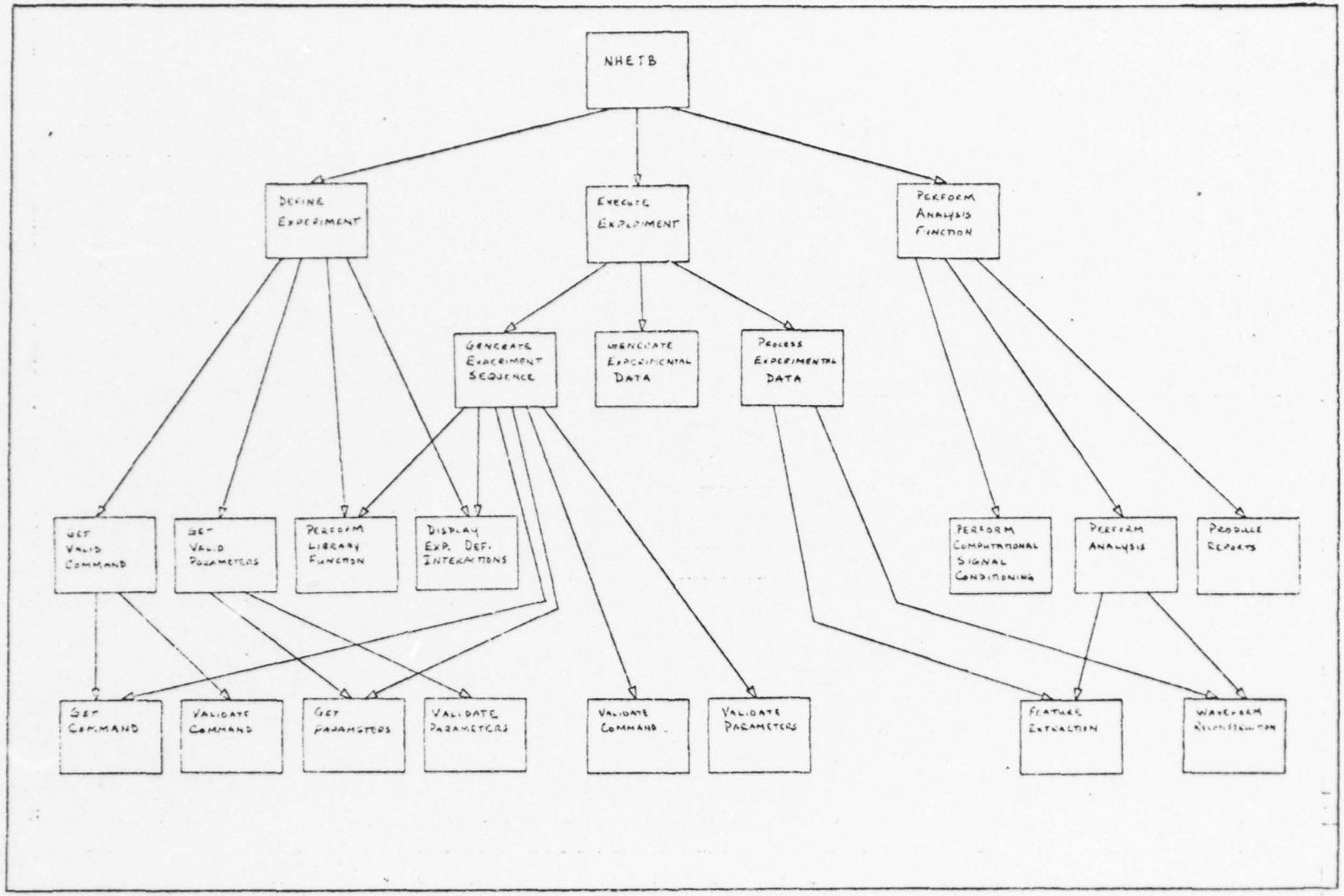

Figure 22. Partial Structure Chart

characteristics implied by the SADT model developed during the previous chapter.

The boxes shown in Figure 22 represent cohesive units of software. In order to perform its assigned function, it is often necessary for a particular software module to reference a subordinate module (e.g., by call to subroutine). Interconnections between modules are used to illustrate this process of subordination. The resulting structure chart represents a well ordered hierarchy of software (Ref 6).

A "first cut structure chart is easily developed from the SADT model. Any one activity node in the SADT model can be implemented with a software module. The modules represented in the decomposition of this node then serve as the subordinate modules referred to in the preceding paragraph. These subordinate modules are also represented by separate nodes in the SADT model. Within these nodes is a further decomposition of function. The previously subordinate modules now serve as "superordinate" modules to the modules represented in the current functional decomposition. This process of subordination continues until the lowest level of modules implement elementary functions and, at this point, the structure chart has been completely defined.

It is then appropriate to examine the structure chart in order to evaluate the quality of design. Some appropriate measures of design are: span of control, scope of effect, scope of control, and fan-in. The use of SADT during the analysis phase of the problem will facilitate the optimization of these design measures.

Span of control refers to the number of immediate subordinate modules under the control of the superordinate module. By keeping the span of control relatively small the designer insures that the hierarchial structure is optimally decomposed, i.e., a low span of control would tend to indicate that functional modules are not fully decomposed and a high span of control would suggest that functional modules have been over-decomposed (does not have enough levels of subordination). The SADT methodology used in this paper facilitates optimal span of control by limiting modular decomposition to a three to six module range. Therefore, adhering to this SADT convention promotes an optimal span of control (Ref 6,7,8).

The scope of effect of a decision refers to the modules that are affected by that decision. Scope of control of a module refers to the range of control of a module and is indicated by the particular module and all of its subordinate modules. One of the principles of design advocated by Constantine and Yourdon is that the scope of effect of a software decision should normally lie within the scope of control of a module that makes that software decision. The use of SADT promotes the optimization of this design measure by distinguishing between control and data inputs. Since the control inputs are emphasized throughout the model, the span of control is well defined during the analysis phase of development. Decisions made within a module can not be made until the module has been activated by the proper control inputs. The results of this decision are normally passed down to lower level modules in the form of control inputs (along with the associated data inputs) so that the lower level modules are activated under

the control of their superordinate modules. Therefore, the use of SADT in this paper has been very useful in maintaining an optimal scope of effect/scope of control structure (Ref 6,7,8).

Fan-in refers to the process of combining "like" modules into single modules. Fan-in is not appropriately described as a measure of design. Rather it is better referred to as a good design technique. During the development of the structure chart it often happens that two or more superordinate modules must access subordinate modules that perform identical functions. Rather than have a separate subordinate module for each superordinate module, the subordinate modules are combined as a single subordinate module. All superordinates then access this one subordinate thereby simplifying the overall design. The SADT model, due to its "tunnel vision" point of view, tends to obscure the possibilities for fan-in. Consequently, fan-in can not take place until the structure chart is developed during the design phase. It is more appropriate that decisions concerning fan-in be made at this stage of development as it allows system modules to be fully defined before common modules are identified. The partial structure chart of Figure 22 is intended to illustrate instances of fan-in.

Software Modules. Most of the software modules developed in the preceding chapter are fairly straightforward, generating control, accounting, or display formating information. Those software modules that relate to the analysis of data are less straightforward and therefore require further elaboration. The purpose of this section is to briefly outline techniques that may be used to accomplish some of these analysis modules.

1. Feature Extraction Techniques. John (Ref 1:50-57) outlines several pattern recognition techniques that are useful in analyzing EEG type waveforms. Among these techniques are: cross-correlation, cross-spectral analysis, discriminant analysis, and cluster analysis.

Cross-correlation and cross-spectral analysis are similar techniques. The first technique takes place in the time domain and the second technique takes place in the frequency domain (with the aid of a fast Fourier transformation (FFT)). In both techniques, a prototype waveform is used as a reference signal. The correlation between the prototype and the candidate waveform is then computed. If the correlation function exceeds a pre-defined threshold value, a positive identification of the candidate waveform is made. Of the two methods the cross spectral analysis technique is a more efficient computation (Ref 1).

Discriminant analysis is also useful in extracting specific waveforms from EEG data (Ref 1;2). In applying the technique, n dimensional prototype or discriminant vectors are defined (can be based on time domain, frequency domain, or collection of other waveform features). Pattern recognition then occurs by computing some measure of similarity between the prototype and measured waveform vectors (e.g., distance measurement between the two vectors) (Ref 1).

Cluster analysis is useful in analyzing a large body of data for which there may be no prototypes defined. In this process, data are grouped into natural clusters (based on one of many available algorithms which set forth the criteria for clustering).

These clusters then serve to classify data according to the features specified by the specific clustering algorithm used. Additionally, this technique may be used in defining prototype vectors for the correlation and discriminant analysis techniques described earlier (Ref 1).

2. Statistical Analysis. In order to provide for a complete analysis of experimental data there should be a wide range of statistical techniques available. Analysis of variance may be used to provide an estimate of the relative influence of different variables on overall variation in performance indices. Hypothesis testing may be used to establish the statistical significance of perceived results obtained from sample data. Regression analysis techniques may be used to express the functional relation between measured variables (Ref 20:82-95; 21:314-342).

3. Signal Validation. In order to insure that the data being collected are valid there should be some means of verifying that the various data channels are working, i.e., that these channels are passing data. This procedure may be as simple as sampling data points from each channel and verifying that the data samples are within acceptable ranges. Also related to signal validation are techniques such as artifact refection or some other arbitrary function defined by the experimenter to detect events that may influence the experimental data or the experimental procedure.

4. Waveform Reconstruction. The use of digital computers in waveform processing requires that waveforms be sampled at discrete time intervals. Sampling theory dictates the minimum sampling rate possible that will still record all of the information contained in the original waveform. When this sampling rate is used it is

possible to reconstruct the original waveform, however, there is some computation involved in this process. The required computation is reported in many textbooks, e.g., Oppenheim and Schafer (Ref 22:26-30).

5. Spectral Analysis. Computation of the spectrum of sampled data can be achieved with the fast Fourier transform (FFT). A survey of algorithms to compute the FFT is contained in Oppenheim and Schafer (Ref 22:284-326).

6. Signal Averaging. Signal averaging is performed by summing successive waveform traces keyed to a specific stimulus. That part of the waveform that is identical for successive traces is enhanced and that part of the waveform that represents random noise is "averaged out". In this type of electrophysiological application the voltage measurements are typically resolved to 9 bit accuracy with an additional 3 bits available for overflow occurring during the summation process. Accordingly 12 bit data words are required to perform the signal averaging computations (Ref 23).

7. Filtering. Filtering may be accomplished by a digital filtering algorithm. The algorithm should be general enough to accommodate the frequency bands of the various electrophysiological signals (Ref 22:195-270; 23:II-10).

Hardware Configuration

The system requirements that have been established in the SADT model developed in the preceding chapter imply certain characteristics of the required hardware system. The requirement for the automation of a variety of complex tasks suggests that the

system should be centered around a main computer. The requirement for hard copy output suggests the need for a line printer and a plotter. Because the system is intended to be interactive during the first two modes of operation and is required to display a variety of information (alphanumeric data, waveform data, etc.) during experiment execution, there is a need for a graphics terminal. With the large number of programs and the high volume of data that is anticipated there is a need to provide for some form of secondary storage. Also because of the large volume of data, along with the variable nature of that data (see Chapter II, Table I), there is a need for a fairly elaborate data acquisition system that can adapt to the changing nature of the data during the course of the experiment. This observation suggests a possible application of microprocessors. In addition, the generation of stimuli and other test controls could also potentially be implemented with a microprocessor. Then, in order to allow for the collection of data from a remote site, there must be provision for a communication link between the subject station and the remainder of the system. The resulting system is illustrated in Figure 23 and is explained in further detail below.

Main Computer. The main computer will be required to perform a wide range of tasks such as pattern recognition, feature extraction, data analysis, test generation, data collection, report generation, interactive graphics, etc. To accommodate all of these tasks will most likely require a memory management scheme such as swapping, overlays, paged memory, segmented memory in which only the required portions of the program reside in the main memory of

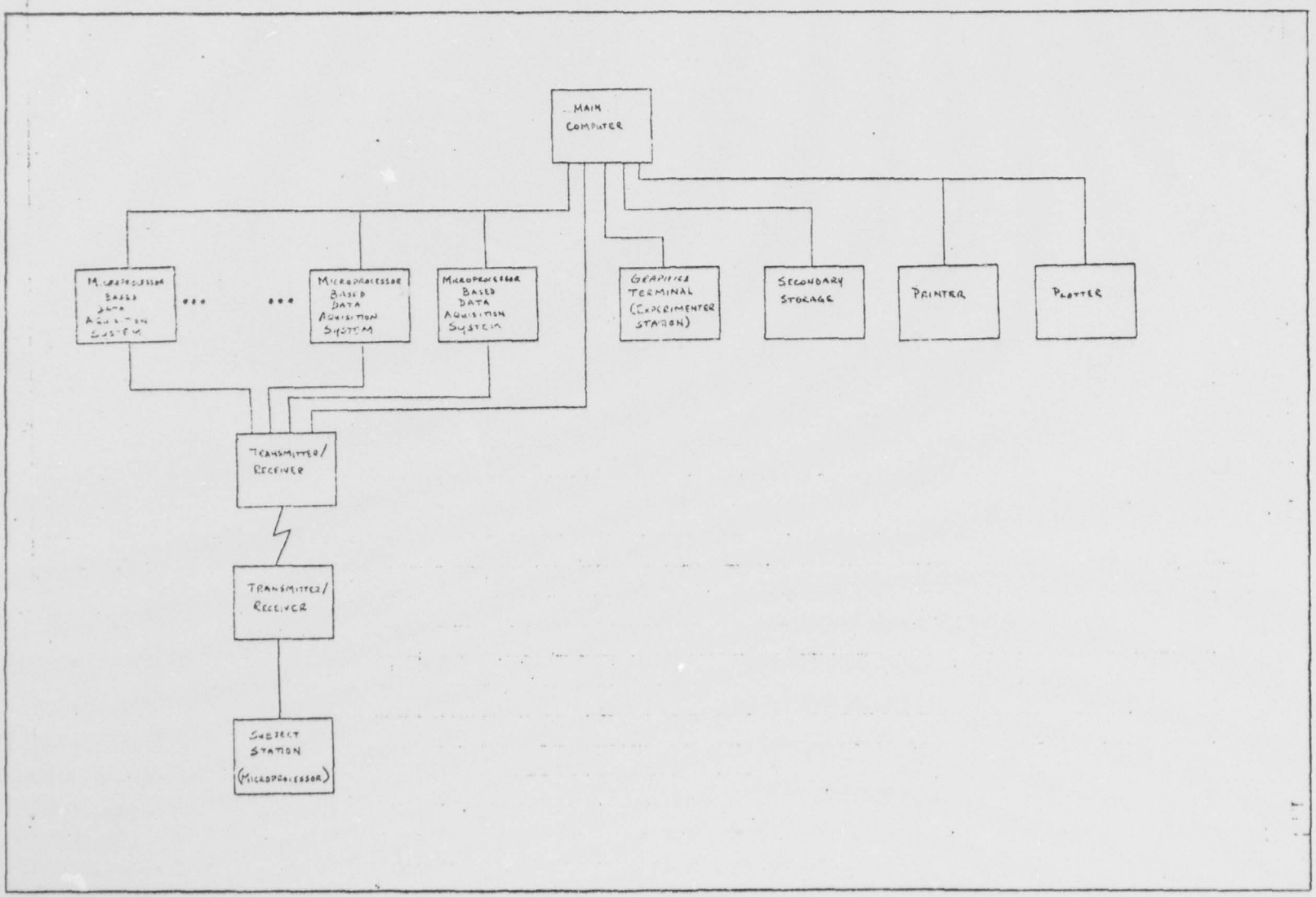

Figure 23. Hardware Structure

the computer. Unused programs or sections of a program would reside in secondary storage until the need for their execution arises. In addition, it should be noted at this point that the link envisioned between the data acquisition system and the main computer may be a potential "bottleneck" in the transfer of data having an impact on the overall response time of the system. There can be up to 100 channels of electrophysiological data plus associated behavioral responses being processed in parallel by multiple data acquisition units. These data are then transferred to the main computer, at the conclusion of the individual tests, where the data are then validated processed and stored. These operations will be required to take place before the generation of the next test (on the order of seconds). In view of these problems, a medium to large scale computer will be required to perform these processing tasks, with the possibility of a multiprocessor capability also being required (Ref 19).

Printer/Plotter. A line printer will be required to generate reports and hard copy outputs of tests that are stored in memory. A plotter will also be required to print out hard copies of the waveform patterns that are collected during the experiment and to generate graphical statistical results such as histograms, frequency distribution, etc. Plotters with mechanically driven pens are available but there can be maintenance problems with mechanical pen drivers. Electrostatic printers overcome these mechanical problems because they do not have any mechanically driven pens. One undesirable feature of the electrostatic printers is the low quality of the paper (roughly equivalent to the

quality of paper used on very cheap reproduction machines). This consideration is primarily cosmetic but should, nevertheless, be considered as it has an impact on the appearance (and reproducibility) of the anticipated final reports.

Graphics Terminal. The graphics terminal must be capable of generating alphanumeric characters as well as continuous patterns such as electrophysiological waveforms. Communication with interactive programs would be most conveniently accomplished through keyboard, programable function keyboard, and, possibly, light pen inputs.

Secondary Storage. Secondary storage will be required for storing idle programs and experimental data. Either tape or disk storage could satisfy this large storage requirement. In tape storage, information is stored sequentially, creating the possibility of fairly long access times if a data record is stored a long distance from the read head on the tape unit. Disk storage, on the other hand, is a pseudo-random access device in that data is stored on several disks with a read head for each disk. In addition, the read heads are capable of moving over the disk so that data records are accessible within a relatively small number of records. With these features disk storage has a much faster mean access/read time over magnetic tape storage. These factors must be weighed against the requirement for real time processing to insure that the secondary storage does not slow down the progress of the experiment. In the absolute worst case, i.e., one hundred channels of brain stem evoked response data or one hundred channels of electromyogram data, there could be between 5 and 15

million bytes of data collected in a 60 second time period and it would be the storage of this data that could potentially slow down system response. A more representative case of the typical data volume would be normal EEG, transient, and steady state evoked responses. In these tests there may be a need to store up to 1.8 million bytes of data collected from 100 channels over a 60 second period (Ref 19).

Microprocessor Based Data Acquisition Systems. Initial data acquisition would best be accomplished through the use of microprocessors. Microprocessors can be programmed to adapt to the changing data rates during an experiment and, through the use of a large local storage area, can serve in a buffering capacity for the large quantities of data being collected. Based on sampling rate and duration of data collection for the electromyogram, there will be a worst case requirement for approximately 150K bytes of buffer storage for each channel of data. This figure may be reduced if it is possible to begin emptying the buffer during the data collection period (this should be possible for the brain stem evoked response, EEG, and transient and steady state evoked responses). Also, it is at this stage of the system that analog-to-digital conversion should take place. Due to the high data rates it appears that there will also have to be many of these microprocessor based data acquisition operating in parallel. Taking typical speeds of microprocessors into consideration it is likely that each data acquisition system will be limited to the processing of four or five channels of data. As noted in the discussion on the main computer, the transfer of data from these parallel

data acquisition systems to the main computer is likely to cause a "bottleneck" and slow down the overall response of the system. There must also be attention given to the processing of the subject's behavioral responses (e.g., subject response key, tracking task, etc.) but these types of data do not pose any major problems as the data rate is relatively slow.

Communication Link. In order to allow for the collection of data from a remote site there will need to be a communication link. Consideration should be given to transmission over telephone lines, coaxial cable, and through the air. For 100 channels of electrophysiological data (and a few additional channels for behavioral responses and information concerning the tests to be administered) there are several standard multiplexing techniques available. Among these techniques are: frequency modulation - frequency division multiplexing (FM-FDM), single side band - frequency division multiplexing (SSB-FDM), and time division multiplexing (TDM). With the large number of channels and the variability in bandwidth of the signals, time division multiplexing may prove to be the most applicable of the techniques since TDM best allows for the possibility of adapting the sampling rate to fit the bandwidth of the signal being transmitted over a particular channel. This technique could be accomplished under microprocessor control and represents the most general approach of the three techniques mentioned above. The instrumentation should be general enough to operate with or without the communication link to allow for a direct link between the subject station and the data acquisition system for those instances when experimentation takes place at the main facility.

Subject Station. The subject station will receive commands to execute specific tests from the main computer and generate the test stimuli and associated test controls. These interactions may proceed under microprocessor control. In addition, the microprocessor could be used to select the required output channels, adjust amplifier gain, adjust filters in accordance with required channel bandwidth, and set up channels for calibration.

Summary

The SADT model developed in Chapter III has served as the starting point for the design developed in this chapter. By augmenting SADT with the principles of structured design, it has been possible to develop a "first cut" at both the hardware and software structure of the Neuropsychophysiological Human Engineering Test Battery. These structures are summarized in Figures 22 and 23.

V Conclusions and Recommendations

Conclusions

The purpose of this paper has been to develop a preliminary design for a Neuropsychophysiological Human Engineering Test Battery. The analysis performed in this paper has served to define the requirements of this system. Once the system requirements were fully defined, the preliminary system design was developed. The techniques for the implementation of this design were drawn from the current technology. As a result, it can be concluded that the desired data processing system is attainable.

The development of a preliminary design for the proposed Neuropsychophysiological Human Engineering Test Battery has been facilitated by a structured approach to design. The technique used in this paper has been a combination of techniques developed by SofTech, Inc. (Ref 7,8) and Constantine and Yourdon (Ref 6). The Structured Analysis and Design Technique (SADT) developed by SofTech has been useful during the analysis phase - deciding what needs to be done. The formalism of this technique proved to be more effective than a somewhat looser approach to analysis taken by Constantine and Yourdon. On the other hand, the principles of structured design advocated by Constantine and Yourdon seem to be able to step beyond the results of SADT and point to a more complete design structure.

Recommendations

Structured Design. It is recommended that the principles of structured design be carried through during the development of the system to implement the Neuropsychophysiological Human Engineering Test Battery. Hardware has been traditionally developed along these lines. The modularization of software, however, is a relatively new concept and as a result, is subject to some controversy. Nevertheless, a structured approach to software development, in the form of structured programming, would be well suited for this particular application.

Structured programming is often praised by software engineers for its ease of modification and maintenance and, almost equally often, condemned by computer programming specialists for occupying too much storage space and taking too much time for execution. In examining these tradeoffs consideration should be given to the organization that will be using the system. At the 6570th Aerospace Medical Research Laboratory (the using organization for this effort) the main thrust of the research effort is directed towards medical research. As a result hardware/software development is intended to be in support of that medical research and not an end in itself. Most of the in-house personnel at AMRL are medically oriented and, as a result, most of the hardware/software development is performed under contract. This situation results in a frequent turnover in technical personnel. As a result, it would be very desirable to design maintainability and modifiability into the proposed test battery to insure continuity in the on-going effort.

System Development. The overall system configuration is illustrated in the previous chapter. One problem that should be solved early in the development phase is the problem of data transfer between the microprocessor based data acquisition systems and the main computer. As was pointed out in the previous chapter, electrophysiological data is collected in parallel by multiple data acquisition units. At the conclusion of a particular test, this data is then passed to the main computer for validation and storage. In cases where the data rate is very high (e.g., many channels of electromyogram or brain stem evoked response data) this transfer may take a considerable amount of time, slowing the response time of the overall system to a point where real time operation is hampered.

More generally the overall system development may be divided up into several levels of effort as follows:

1. Development of main facility. This effort should include selection of the main computer, secondary storage medium, printer, plotter, graphics terminal, and the establishment of an Operating System for this facility.

2. Development of data acquisition capability. This effort should include the development of the experiment station (under microprocessor control) and the microprocessor driven data acquisition systems (and programming of these systems).

3. Development of software. This effort should include the programming of interactive graphics routines, test sequencing, data transfer, data validation, data analysis, report generation, etc.

4. Development of communication link. This effort should

address the selection of type of communication link, development of modulation technique and development of multiplexing technique.

5. Maintenance and modification. Maintenance and modification refers to the effort required to keep the test battery up to date and functional. This effort will require technical personnel capable of repairing malfunctions as they occur and implementing modifications as the system evolves.

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Appendix A

User's Manual

Introduction

The purpose of this user's manual is to describe the kinds of user interactions required to operate the Neuropsychophysiological Human Engineering Test Battery. Since this test battery will probably be a very complex system, it is anticipated that there will be several levels of users. First, there will be the system programmers/technicians who will develop and maintain the system. Next, there will be technical research assistants who will be required to format, sequence, and check out the various tests before an experimental run and will be responsible for generating the final results after the experimental run. And, finally, there is the experimenter who will need to interact with the system to monitor progress during actual experiments with human subjects.

From the above discussion it can be seen that there are three major phases in performing an experiment. First, there is the initial test definition phase in which the various tests and their sequencing are determined. Next is the experiment phase in which the tests are performed and the resulting data are collected. Finally there is the analysis phase in which the data are analyzed. These three phases will be reflected in the following three modes of system operation: test definition phase, experiment phase, and analysis phase.

Test Definition Mode

The test definition mode allows the user to define the parameters of the various tests to be used in a particular experiment. When in this mode, the system will output a message indicating that it is in the test definition mode. The user may then proceed to define the overall experiment by entering the following commands: Test Library, Test Sequence Library, and End Test Definition. During this procedure invalid commands will cause an error message to be output and a request for the command to be re-entered. A discussion of each of the commands and the various options under these commands follows.

Test Library. Invoking this command allows the user to input, store, recall, and modify the parameters of the individual tests to be used in a specific experiment. After the Test Library command has been entered, the user may then choose from the following options: Create Test, Store Test, Purge Test, Display Test, List Test, Alter Test, and Print Test.

The Create Test command causes the system to generate a request for Test Type. The user will then respond with one of the following Test Types: EEG (electroencephalogram), TAER (transient auditory evoked response), TVER (transient visual evoked response), SSVER (steady state visual evoked response), BSR (brain stem evoked response), EKG (electrocardiogram), EMG (electromyogram), or GSR (galvanic skin response). Once this command has been entered the user will be given three option fields: Stimuli, in which stimulus characteristics are defined, Channels, in which channel characteristics are defined, and Display Control, in which the intermediate

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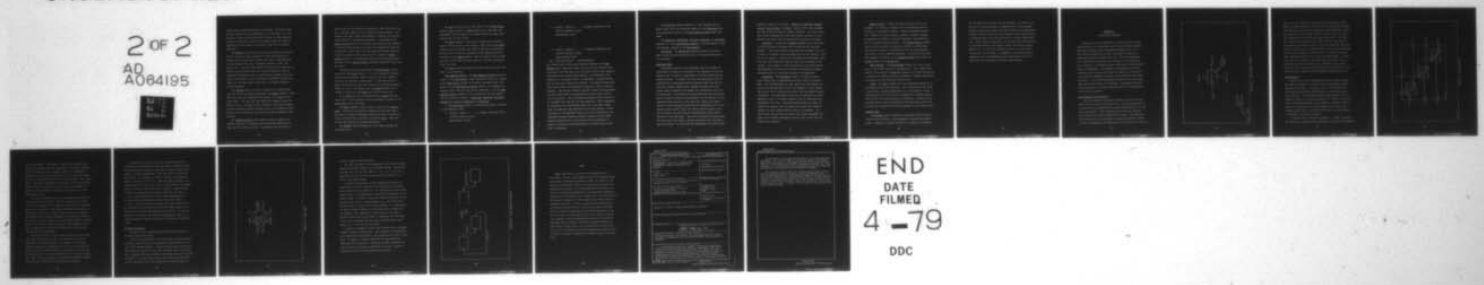

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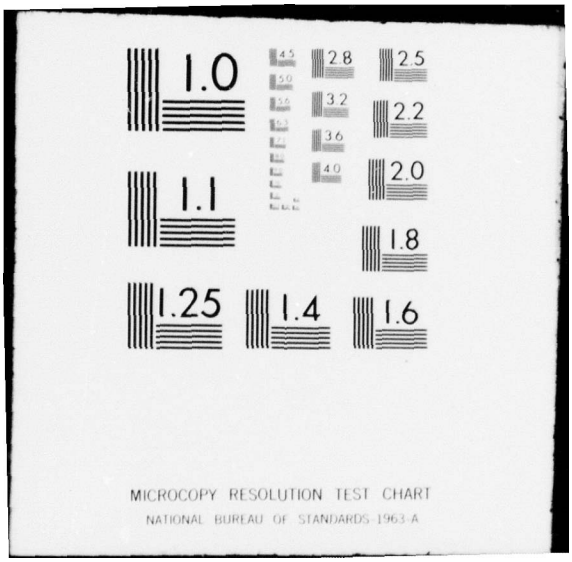
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MICROCOPY RESOLUTION TEST CHART
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output during experiment execution is defined. The basic format of these options will vary depending on the test type, e.g., the transient visual evoked response will require a fairly extensive listing of characters to be used as stimuli whereas the electroencephalogram will require very little in the area of stimulus definition.

The Stimuli option will allow the user to define the various stimuli used in the test according to such characteristics as stimulus (visual character, auditory tone, etc.), type (critical or non-critical item, etc.), intensity, contrast, focus, frequency, etc. Also under this option the user will be required to define stimulus dynamics such as: stimulus duration, stimulus conditional termination (e.g., if the subject responds before the end of the stimulus, it may be desired to terminate stimulus presentation), and next stimulus onset (e.g., at fixed intervals or random intervals).

The Channels option is used to identify the channel characteristics of the test being formed under the Create command. Under this option the user identifies the channels to be used by electrode number. The user will then define the required channel dynamics such as: duration of data collection, conditional trigger of data collection (usually stimulus onset), and conditional termination of data collection, e.g., when the subject responds to the stimulus.

The Display Control option allows the user to specify the channels that will be displayed during experiment execution and their time and amplitude scales. In addition, the user will be

able to specify the features of interest for that particular test, e.g., the P300 component of the transient evoked response. The software will then compute the features of interest and identify these features on the displayed waveform. The purpose of the Display Control option is to provide the researcher with feedback to evaluate the progress of the test during experiment execution. Consequently, there will not be any extensive analyses performed under this command. There will also be an identical Display Control command in the experiment mode in which the experimenter may over-ride the Display Control parameters specified during test definition.

The above discussion constitutes the Test Library interactions under the Create command. It is not required that entries be made for each option. When an entry is not made a default value will be assigned to that option. At the conclusion of these interactions the user may access any of the other commands simply by issuing the command (even the Create command if he decides to write over the Create file without storing it).

In the Store command, the contents of the Create file are identified by a user supplied index and permanently stored in the Test Library under that index.

The Purge command is used to erase a test from the Test Library. The test to be purged is identified by the test index. That test will then be displayed and the user will be required to verify that that test is the one he wanted to Purge. Upon verification the test will be erased from memory.

The Display command followed by a test index displays the identified test.

The List command will list the indices in the Test Library either by All indices or by Type indices, e.g., BSR, EEG, etc. The purpose of this command is to inform the user of tests that already exist in the library.

The Alter command is used to make corrections or modifications to tests already in the library. After issuing the Alter command, the user supplies the index of the test to be altered. At this point he then has available all the commands that were available in the Create command. The only changes that are made are those changes that the user types in. All other parameters remain the same.

The Print command followed by the test index will cause the test to be printed out.

Test Sequence Library. The Test Sequence Library command is similar to the Test Library command except that where the purpose of the Test Library command is to define individual tests, the purpose of the Test Sequence Library command is to assemble and sequence these tests into the overall experiment. Once the Test Sequence Library command has been entered the user may respond with the following commands: Create Seq, Store Seq, Purge Seq, Display Seq, List Seq, Alter Seq, and Print Seq.

In the Create Seq command, the overall experiment is defined in the following manner:

1. ($Index_1$ + $Index_2$ +... ...+ $Index_m$) conditional f(x)
   artifact rejection on/off
   stop sequence on/off

2. ($Index_1$ + $Index_2$ +... ...+ $Index_n$) conditional f(x)

artifact rejection on/off

stop sequence on/off

.

.

.

N. ($Index_1$ + $Index_2$ +... ...+ $Index_p$) conditional f(x)

artifact rejection on/off

stop sequence on/off

N+1. Initiate Analysis automatic/manual

The indices refer to tests that have been defined in the Test Library mode. Under this format there can be more than one test occurring at the same time, e.g., transient visual evoked response and steady state visual evoked response. The conditional f(x) parameter is an optional field. It represents a computed branching from the normal sequence of testing. If omitted, testing will proceed according to the sequential ordering of tests in the experiment. The artifact rejection parameter allows the experimenter to reject trials that are contaminated by excess motor activity such as eye blink. The stop sequence parameter causes activity to be suspended after the test has been completed. Normal sequencing is resumed when the experimenter enters the start/stop command under the experiment mode described in the next section. At the conclusion of the experiment there is one final statement in the experiment sequence indicating whether analysis of data should proceed automatically at the conclusion of the experiment or whether it should be initiated manually by punched cards at the user's convenience.

The Store Seq command followed by a user supplied test sequence index causes the experiment defined in the Create Seq file to be permanently stored in the Test Sequence Library under that index.

The Purge Seq, Display Seq, List Seq, Alter Seq, and Print Seq commands act on the Test Sequence Library in the same manner as the corresponding commands of the Test Library.

End Set-Up. The End Set-Up command terminates the set-up mode of operation and transfers control to the executive program of the system.

Experiment Mode

The primary purpose of the experiment mode is to allow the experimenter to monitor the progress of the experiment during its execution and to modify the experiment if testing should yield unexpected results. To achieve this goal the experimenter will be supplied with a programable function keyboard (PFK) that will accept basic control commands and a graphics terminal that will accept control parameters and display the intermediate results of the experiment. Upon entering the experiment mode the system will output a message telling the experimenter that the system is in the experiment mode and will, at the same time, request the experimenter to enter information describing the experiment such as test sequence index, subject name, age, social security number, etc., and an optional narrative section describing any unique characteristics of the experiment. When this information has been input, the system will then output a message indicating that the experiment may proceed. At this point the experimenter may initiate the

following commands via the PRK: Calibrate, Start/Stop, Display Control, Print Display, and Abort. Options under these commands are then entered through the graphics terminal. As in the set-up mode invalid commands will cause the system to generate an error message and request that the experimenter re-enter the command.

Calibrate. Invoking the Calibrate command causes the system to check electrode resistances and to calibrate the electrode channels. While this command could almost be included in the set-up mode it is called in the experiment mode for two reasons. First of all the subject is usually not available until experiment execution time (the calibration requires that he be connected to the system). And secondly, it may be desired to re-calibrate during the experiment to verify that electrode resistances and channel characteristics are consistent throughout the experiment.

Start/Stop. The Start/Stop button on the PRK is used to start testing and to suspend/resume activity during the experiment. When the experiment has been stopped the experimenter may wish to make modifications to the test sequence. He may modify the current test by indexing the current test and typing in those corrections. The experimenter will also be allowed to interpose additional tests or to delete existing tests by identifying the appropriate test index. When these modifications are made, the current test sequence will be updated to reflect those changes; however, the test sequence library will not be updated. As a result these changes will only affect the current experiment and none of the following experiments that may also access this particular test sequence.

Display Control. During the actual execution of the experiment it is desired to display what has previously been referred to as intermediate results. These intermediate results are: readout of current stimulus, readout of subject response (if applicable), display of selected waveforms, and identification of selected waveform features. The Display Control command will be used to specify the specific channels to be displayed, the waveform features to be identified, and the time and amplitude scales for the waveforms displayed. It should be noted that this command is identical to the Display Control option under the Create command in the Set-Up mode.

Print Display. The Print Display command will cause a hard copy of the current display to be printed out. This command will only be active during the Stop mode (otherwise it would be possible to print out the display during the middle of a display update when the display has been partially written over).

Abort. The Abort command causes the experiment session to be terminated and all data discarded. This command would most likely be used during system checkout when it is not desired to retain collected data or in the case of an equipment or software malfunction in which the collected data are inaccurate. Normally the experiment session will be terminated at the conclusion of the last test and the collected data will be prepared for the analysis mode.

Analysis Mode

The Analysis mode of operation is initiated either automatically at the conclusion of the experiment or manually by punched cards. Automatic vs manual initiation of analysis is determined

by a statement at the end of the test sequence. In either case, the data to be analyzed will be specified and a pre-programmed analysis package will generate the final output of the experiment. Automatic analysis initiation will normally be used when analysis is performed only on the data collected in a single experimental run. Manual analysis initiation, on the other hand, will normally be used when analysis will compare results from several experimental runs. In this case, analysis can not occur until after all the data are collected. Consequently, the analysis mode is suppressed until the experimenter has collected all of the required data and initiated the analysis mode manually.

Appendix B

Reading SADT Diagrams

The purpose of this appendix is to give the reader a basic understanding of the conventions used in the Structured Analysis and Design Technique (SADT) developed by SofTech, Inc. For a more thorough explanation of SADT, the reader is referred to documents produced by SofTech (Ref 7,8). The SADT methodology is a technique for describing the structure of a system (hardware, software, or combination) and is most useful in the analysis phase of development. The technique, as developed by SofTech, examines system structure from both the viewpoint of the activities needed to implement the system and the data that the system operates on. For reasons discussed in Chapter III of this paper only the activity diagram was developed. Consequently, the following discussion is directed primarily towards an understanding of the activity diagram.

Basic Element of the Language

The basic element of the SADT language is a box with arrows entering or leaving the box (Figure B-1). This box represents an activity that is performed by the system being described or by one of its subsystems. Arrows entering the activity box from the left hand side are used to represent data inputs. Upon entering this activity box, the input data is transformed and the results of this transformation are indicated by arrows leaving the activity

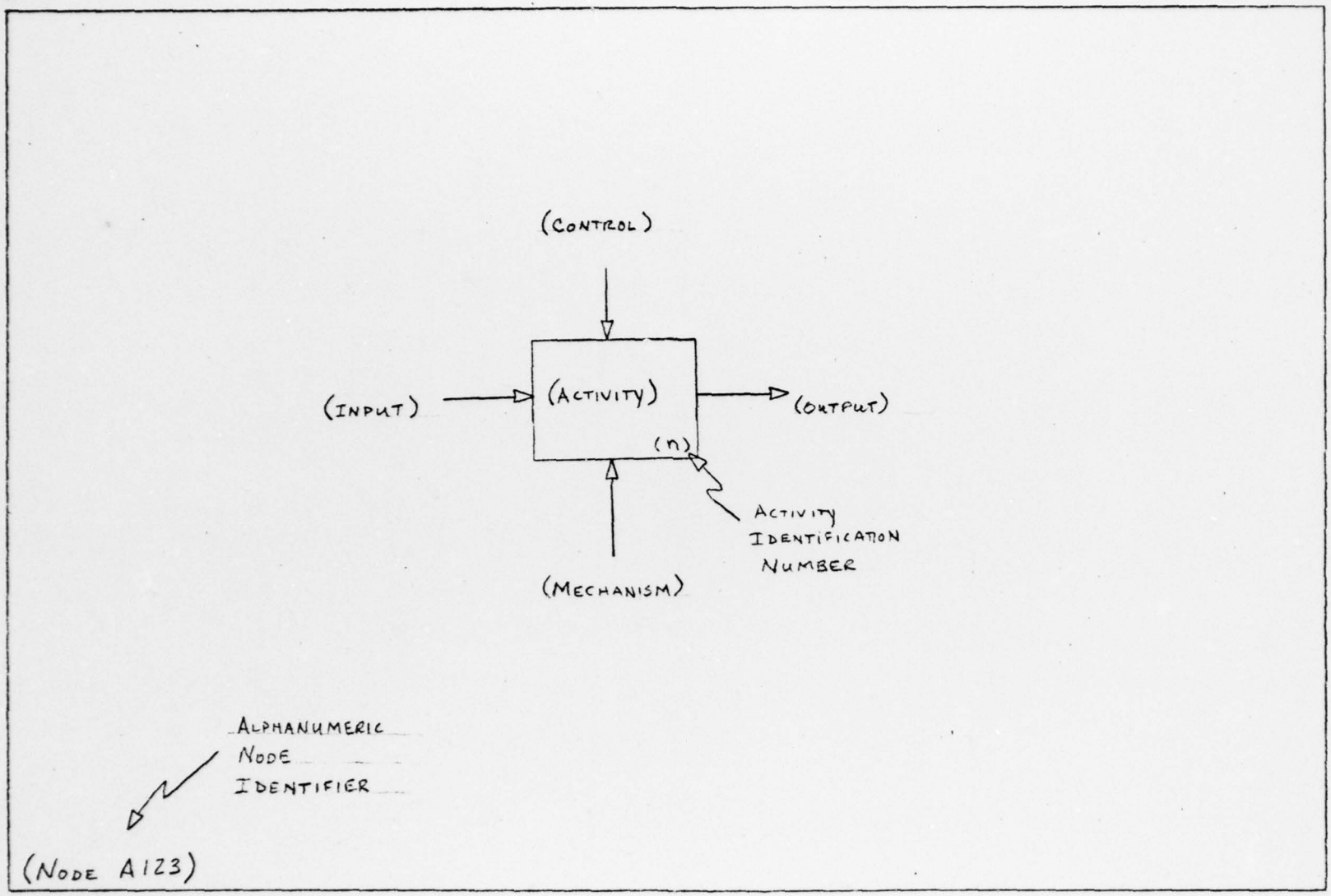

Figure B-1. Basic Element of SADT

box on the right hand side. During this transformation process there are arrows entering at the top of the activity box to represent data inputs which are not themselves transformed into output data quantities but, instead, serve to control or constrain how the transformation of normal data inputs take place. The fourth arrow entering the activity box at the bottom is often omitted. The quantity represented by this arrow is the mechanism that operates on the data, i.e., it describes who or what is performing the activity being modeled. Inside the box is a descriptive phrase which identifies exactly what activity is taking place. In addition, there is a number in the lower right hand corner used to identify a particular activity box in relation to the overall SADT structure. Interconnections between activity boxes via SADT arrows is used to indicate the relationship between activities.

SADT Structure

Figure B-2 is used to illustrate the basic concept of SADT. This figure represents not one, but several SADT drawings superimposed on one another. The intent here is to illustrate the relationship of individual SADT drawings to the overall hierarchial structure. In discussing modules within modules it is convenient to refer to the general module as the "parent" module and the more detailed breakdown of this module as "children" modules (note that a module can be a parent module to its lower level children modules and, at the same time, itself be a child module to its higher level parent module).

At the very top of the SADT structure is a single box describing the overall system and the relationship (via inputs and outputs)

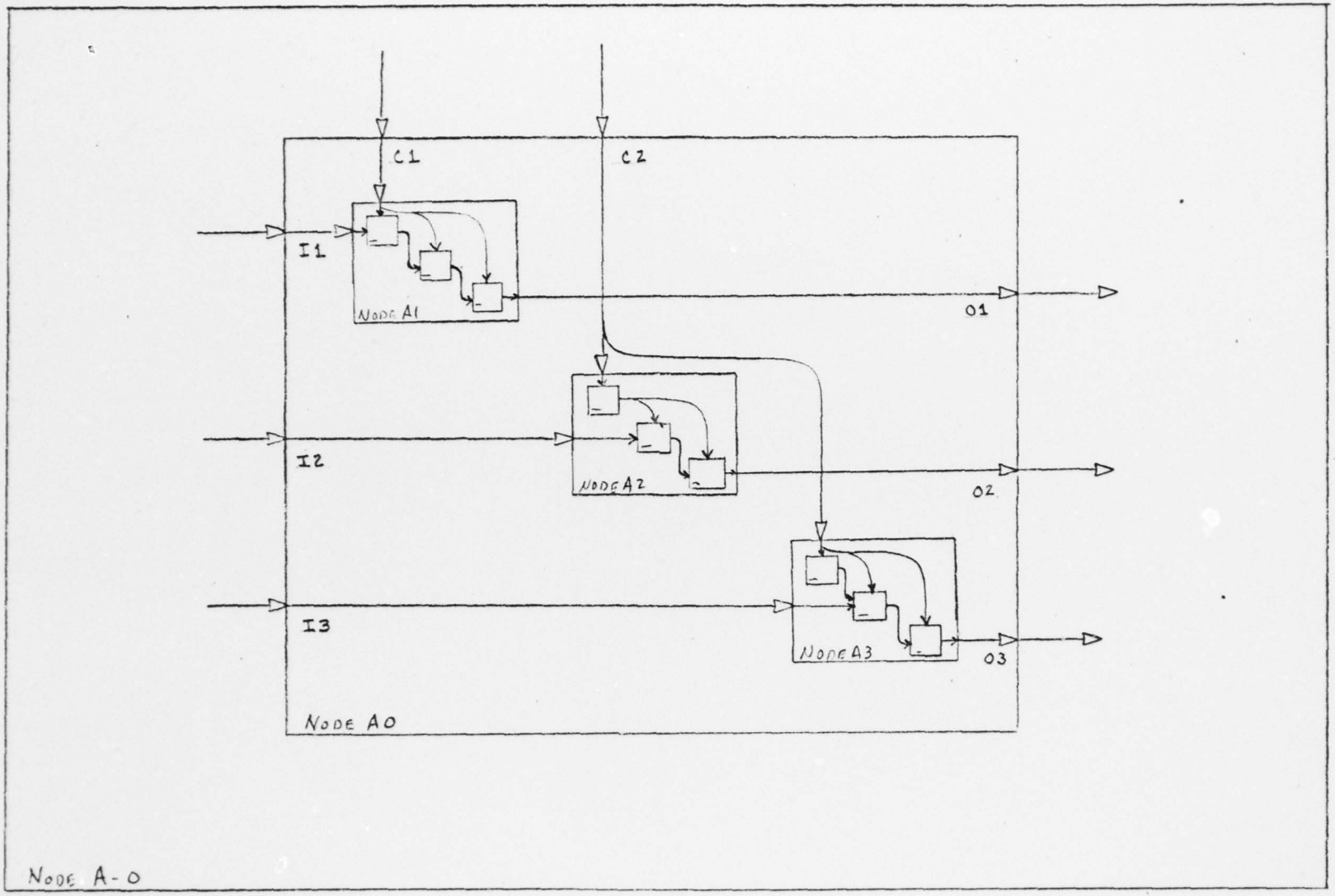

Figure B-2. SADT Structure

to its environment. Since there is only this one activity box there are no numerical entries appearing in the lower right hand corner of the activity box, however, there is an alphanumeric designation of A-0 (read "A minus zero") in the lower left hand corner of the drawing on which this activity appears. This alphanumeric designation identifies the position of the drawing in the SADT hierarchial structure and the fact that the drawings are indicating the breakdown of activities (the letter "A" in the alphanumeric entry).

In order to describe the activities taking place within the single box of the A-0 node of the SADT structure the A0 (read "A zero" and appearing in the lower left hand corner of the drawing) node is developed. This drawing represents the general activities (in the form of activity boxes) required to accomplish the overall system function represented in the previous drawing. The arrows from the A-0 node are carried through into the activity boxes in the A0 node thereby presenting a more detailed view of what is done with the input data quantities and how the output data quantities are generated.

The activity boxes in the A0 node are numbered in the lower right hand corner of the activity box and serve as a key for identifying succeeding drawings. For example, if the reader wished to examine the decomposition of box 1 in the A0 node, he would look for a drawing labled A1 in the lower left hand corner of the drawing ("A" for activity model and "1" for box 1 of node A0). The A1 drawing would then illustrate the functional decomposition of the A1 node that was represented in node A0.

To follow the activities through to successively more detailed levels of decomposition the reader would locate the number of the particular activity box he wishes to examine, append that number to the node designation in the lower left hand corner of the drawing. For example, the boxes in node A0 are further detailed in drawings A1, A2, A3... When the reader examines one of these drawings, say A1, he may wish to further examine the decomposition of activity boxes within the A1 drawing. These detailed drawings are represented in drawings labled A11, A12, A13, ... A1n. These drawings may be even further decomposed, e.g., A12 may be further detailed in drawings A121, A122, A123, ... A12n. This process continues until the analyst feels that he has decomposed the activities in sufficient enough detail to illustrate the nature of the problem being described. In order to indicate to the reader just where the decomposition ends, it is usually helpful to include an index at the beginning of the SADT model.

Specific Conventions

Figures B-3 and B-4 represent specific conventions used in the SADT model of this paper.

Figure B-3 represents the use of ICOM (Input, Control, Output, Mechanism) codes used to trace quantities represented by the various arrows between drawings. On any particular SADT activity box these codes are implicit in the order that they enter or leave the box. Therefore they do not appear in the original box but are used as labels in the lower level drawing that details the activities of this originating box. This convention is primarily used as

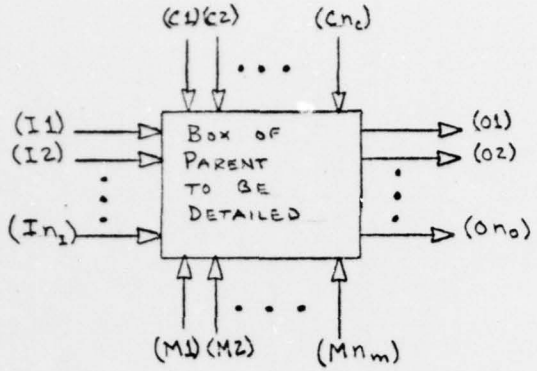

Figure B-3. ICOM Codes

an aid in reading between drawings.

The ICOM code appears on the drawings next to the arrow that represents the data quantity of the "parent" module. The resulting label has the form ⟨Ki⟩, where K is an I, C, O, or M and i represents the ith arrow of the particular data type (I, C, O, or M) of the parent module.

In textual descriptions of SADT diagrams data arrows are referenced by the ⟨Ki⟩ convention when discussing the relationship between the data quantity as it is represented in the parent module and as it is represented in the child decomposition of the parent module. In instances where the textual description focuses on SADT arrows within a single drawing (i.e., the relationship between parent and child is not being examined) it is appropriate to refer to arrows formally by the notation that is implicit in the drawing. This reference is in the form of ⟨jKi⟩ where j represents the activity box number, K represents the ICOM designation, and i represents the ith arrow of the particular data type (I, C, O, or M) of the jth module.

Figure B-4 represents a short hand notation used to represent feedback between activity boxes. This convention is represented by a double pointed arrow with a dot appearing next to each arrowhead. In addition, the data quantities are represented by a (data1)/(data2) designation. The data1 quantity represents the name of the originating data quantity and the data 2 quantity represents the name of the feedback data quantity.

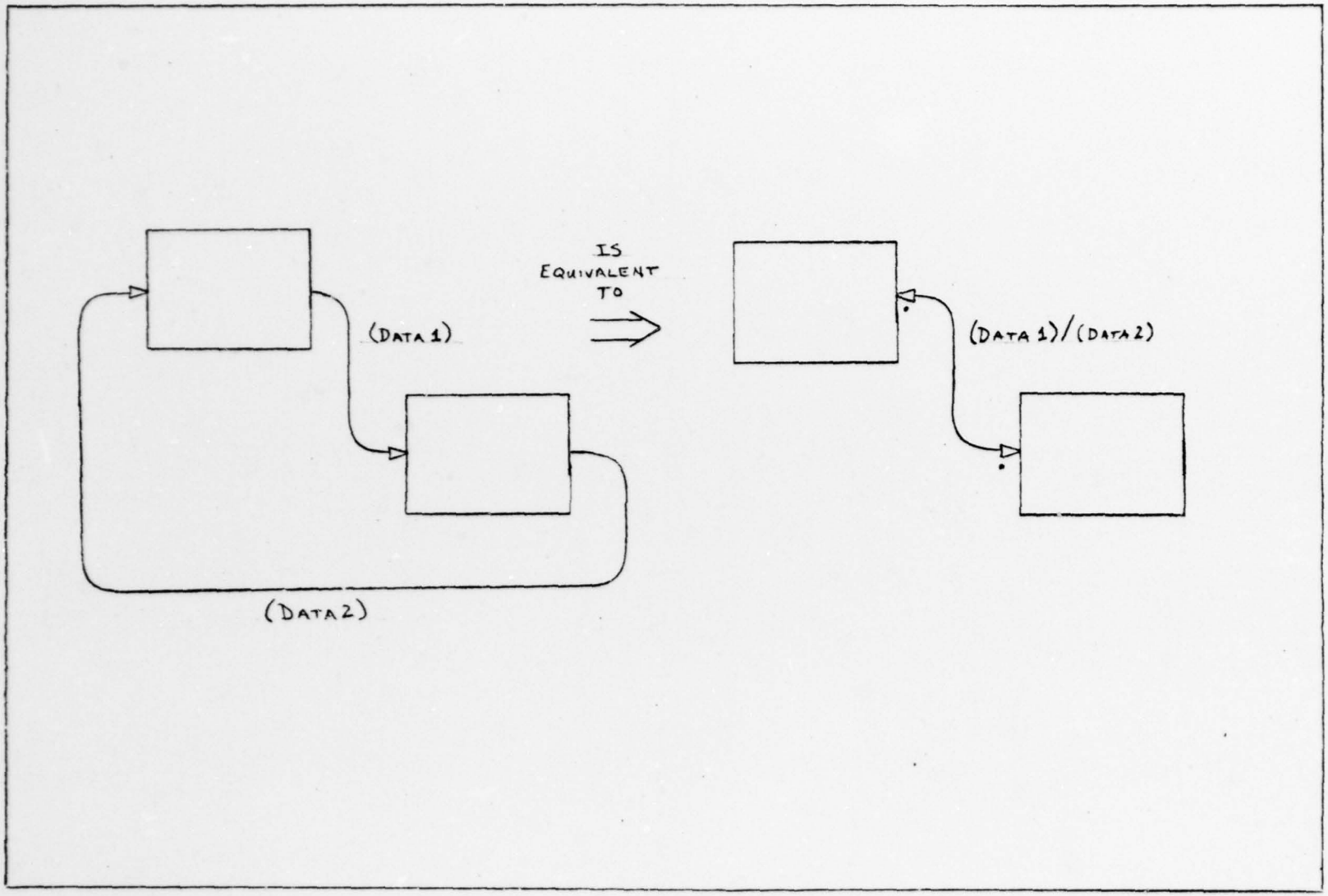

Figure B-4. SADT Feedback Convention

VITA

Robert Edward Norris was born on 10 September 1951 in Cocoa Beach, Florida. Upon graduation from the Cardinal Gibbons High School in Baltimore, Maryland in 1969, he enrolled in the Electrical Engineering program at the University of Maryland in College Park, Maryland. As an undergraduate he held part-time jobs as an engineering technician in the Biomedical Engineering Laboratory at the University of Maryland and in the Laboratory for High Energy Astrophysics at NASA Goddard Space Flight Center in Greenbelt, Maryland. In 1974 he graduated from the University of Maryland with high honors, receiving a bachelor of science degree in Electrical Engineering and an ROTC Commission in the U.S. Air Force. He Then reported for active duty as a simulation engineer at the Human Engineering Division of the 6570th Aerospace Medical Research Laboratory at Wright-Patterson Air Force Base in Dayton, Ohio. At the conclusion of this assignment in 1977, he entered the graduate engineering program at the Air Force Institute of Technology at Wright-Patterson Air Force Base.

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A preliminary design for a computer based Neuropsychophysiological Human Engineering Test Battery is developed. This system provides for the automated administration of a battery of tests designed to measure human performance as reflected in the electroencephalogram, cortically evoked potentials, and other psychophysiological measures of performance. This system will be capable of recording and analyzing up to 100 channels of electrophysiological data.

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System design is developed through the use of structured design techniques. The initial stage of the design process, the requirements definition phase, is developed with the aid of the Structured Analysis and Design Technique (SADT) developed by SofTech, Inc. The remainder of the design, the actual preliminary design, is developed through the use of general structured design techniques.

The resulting system design is centered around a main computer which coordinates system activities, stores experimental data, analyzes experimental data, and generates displays and final reports. Initial data collection is achieved through the use of multiple microprocessor based data acquisition units. The subject station, where stimuli are generated and subject responses take place, is also under microprocessor control. Provision is also made for transmitting data from a remote location.